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MINUTES AND PROCEEDINGS
of the Thirty-fifth meeting of the
ARMED FORCES-NRC VISION COMMITTEE
November 3-5, 1954

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MEDICINE

Sunnybrook D.V.A. Hospital

Toronto, Ontario, Canada

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of the Thirty-fifth meeting of the
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1959

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AGENDA OF THE 35th MEETING

AND

INDEX TO THE PROCEEDINGS

On November 3 the Committee made a tour of the Institute of Aviation Medicine of the Royal Canadian Air Force. A welcoming address was given by Dr. O. M. Solandt, Chairman of the Defence Research Board of Canada, in behalf of the Department of National Defence of Canada and the Defence Research Board.

OTHER PAPERS PRESENTED:

Dr. W. J. Crozier presented a paper entitled "The Time-Intensity Function." A complete copy of this report is not available for publication in this Proceedings volume.

Dr. L. H. Beck gave a presentation entitled "A Measure Of Color Contrast, Border Contrast, and Irradiation in the Visual Field." There is no text of this paper available for this Proceedings volume.

Dr. C. P. Crocetti made a presentation entitled "Some Problems Encountered in the Visual Display of Intelligence." There is no text of this paper available for publication in this Proceedings volume.

Dr. Max W. Lund presented a paper entitled "Progress in the Time-Compression Technique", the text of which is not contained in this Proceedings volume since the paper is CONFIDENTIAL.

Dr. J. Clement McCulloch requested that a document entitled "Report of the Visual Panel of the Defence Research Board: Problems Submitted by the Services" be read into the Proceedings. This text is not contained in this Proceedings volume since the document is CONFIDENTIAL.

Lt. Cmdr. H. P. Leidl, RCN, presented a paper entitled "RCN Visual Problems", the text of which is not contained in this Proceedings volume since the paper is CONFIDENTIAL.

Capt. F. J. Murphy, Canadian National Defence Headquarters, presented a paper entitled "Canadian Army Visual Problems", the text of which is not contained in this Proceedings volume since the paper is CONFIDENTIAL.

ARMED FORCES-NRC VISION COMMITTEE

Minutes of the Thirty-Fifth Meeting

November 3-4-5, 1954

Toronto, Ontario, Canada

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ACCOMMODATIVE RESPONSE OF THE EYE OF AN AGED CAT TO ELECTRICAL STIMULATION OF THE CILIARY GANGLION

School of Optometry, University of California, and
Aero Medical Laboratory, Wright Air Development Center

Elwin Marg and Johnie L. Reeves

Introduction

It is well known that man's power of accommodation is progressively and continuously reduced throughout most of his life. He is probably born with almost 18 diopters of potential accommodative amplitude. At 10 years of age the amplitude is about 15 diopters and it is generally believed that it reaches a minimum of 1 diopter or less at about 60 years.

What is known about accommodative amplitude and age in animals other than man? * Although reference to presbyopic animals, indicating a reduction of accommodation with age, may be found in the literature, it appears to be based on anthropomorphism rather than experimentation. We have been able to find no evidence that animals other than man exhibit a reduction of accommodation with age.

We were fortunate in obtaining for experimental use a cat unquestionably known to be 15 years old. This animal was used in an experiment similar to those of a previous study on a group of young cats.[1] The question was, does the accommodative amplitude in the aged cat differ significantly from that in young cats? If the aged cat's amplitude is significantly lower, then perhaps the process which reduces accommodative amplitude is similar to that in man. If the amplitude is not significantly reduced, it might be of interest to future investigators of presbyopia in man to determine why cats do not suffer a similar affliction.

Previous Experiments on Young Cats

In a previous paper[1] the accommodative response of the eyes of young cats to electrical stimulation of the ciliary ganglion was determined. Bipolar silver electrodes were placed on the ciliary ganglion. Voltage and frequency of the stimulus were varied systematically with a Grass Stimulator. The accommodative response was measured directly in diopters with a Rodenstock Eye-Refractometer. In order to avoid pupillary constriction upon stimulation (with the resultant interference of refraction) the eye was partially iridectomized some weeks before. Two or more extra-ocular muscles were severed to prevent eye movement upon stimulation of the ciliary ganglion. Anesthesia was generally provided by nembutal although decerebration was used and it was demonstrated that the drug did not appear to affect the results. The reader is referred to the original paper[1] for the curves and for a treatment of the possible significance of the data.

The Present Experiment on the Aged Cat

The subject was a 15-year-old neutered domestic shorthair cat which had been in excellent health except for several infected teeth extracted some months previously. The eyes were partially iridectomized and the experimentation was done after the animal had completely recovered from this surgery. Under nembutal anesthesia the ciliary ganglion was exposed. The inferior rectus and inferior oblique were severed to prevent eye movement upon stimulation. The silver bipolar electrode was placed across the ganglion and the wound was clamped shut. Stimulation was provided by a Grass Stimulator set at 1 msec.

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* Although the ability to accommodate is well established in various mammals from stimulation experiments, there is no experimental evidence available as yet to show that mammals other than the primates actually accommodate in the course of their normal activity.

pulse duration with biphasic waves. This is essentially a differentiated rectangular wave with the discharge timed so that zero potential is reached at the time the negative phase or latter half of the cycle begins. The pulse duration is the duration of an original square wave.

Accommodative response was measured with a Rodenstock Eye-Refractometer. There is no need to use an artifical pupil (to minimize aberrations by limiting the area of the eye refracting media) since the entrance pupil of this instrument is much smaller than the exit pupil of the iridectomized eye.

The cornea was flushed regularly with a 1-1/2% sodium bicarbonate solution to help maintain its optical quality in the absence of normal lid movements and lacrimation.

Results

Figure 1 shows the relation between stimulus voltage at 25 cycles per sec. and the refractive state of the eye in diopters referred to the spectacle plane. It appears to be essentially linear over its gradation length of 2-1/2 volts and then levels off. The accommodative amplitude is about 1.3 D.

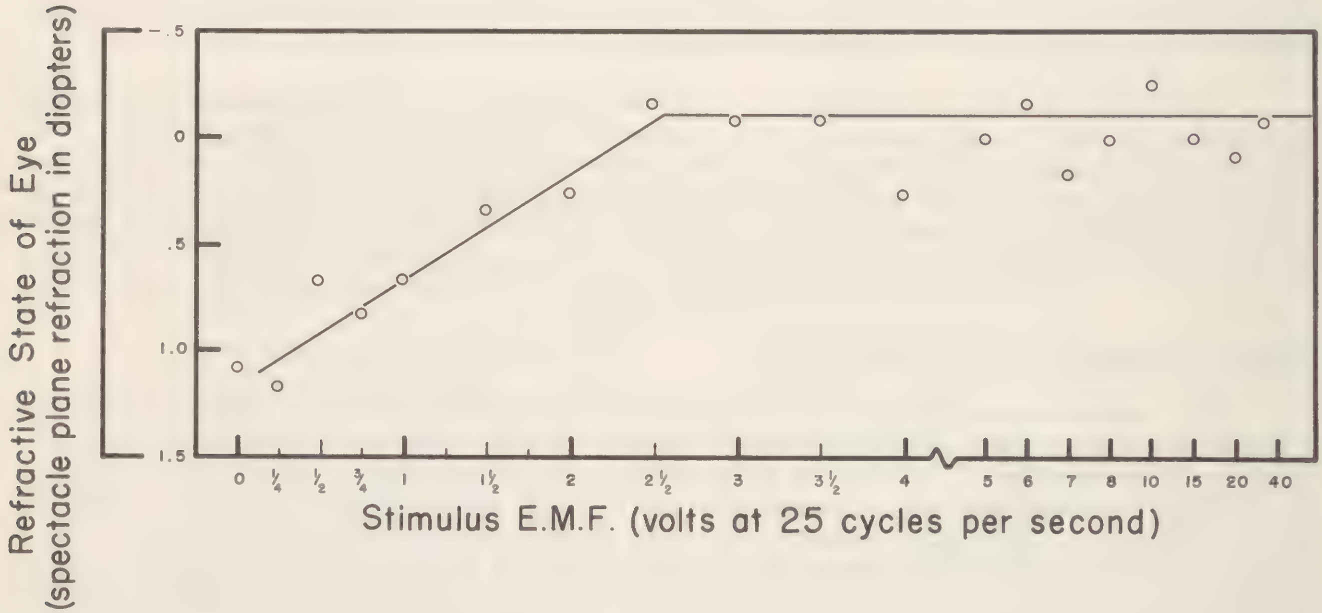

Figure 1

Figure 2 shows the results of varying stimulus frequency at 10 volts. With the exception of one stray point at 6 cycles, the relationship is essentially linear over its gradation range from 4 to 30 cycles. The amplitude of accommodation is 1.5 D.

Discussion

The stimulus voltage curve (Figure 1) of the aged cat has no obvious characteristics that distinguish it from similar curves of younger cats. Although the maximum gradation voltage of 2-1/2 is low compared to that of 5 volts of Figure 1 for the young cats, the value appears to be within the range of normal variation, since some young cats also showed higher voltage sensitivity. Furthermore, the voltage sensitivity may be dependent in part on the placement of electrodes and the short-circuiting effect of surrounding tissue and fluids so that it cannot be depended upon as a reliable absolute measure between two different preparations. The accommodative amplitude is low compared with the approximate 2 D. values from young cats. Hence, there may be a reduced amplitude of accommodation in the aged cat indicated by this curve. This topic will be discussed in detail later.

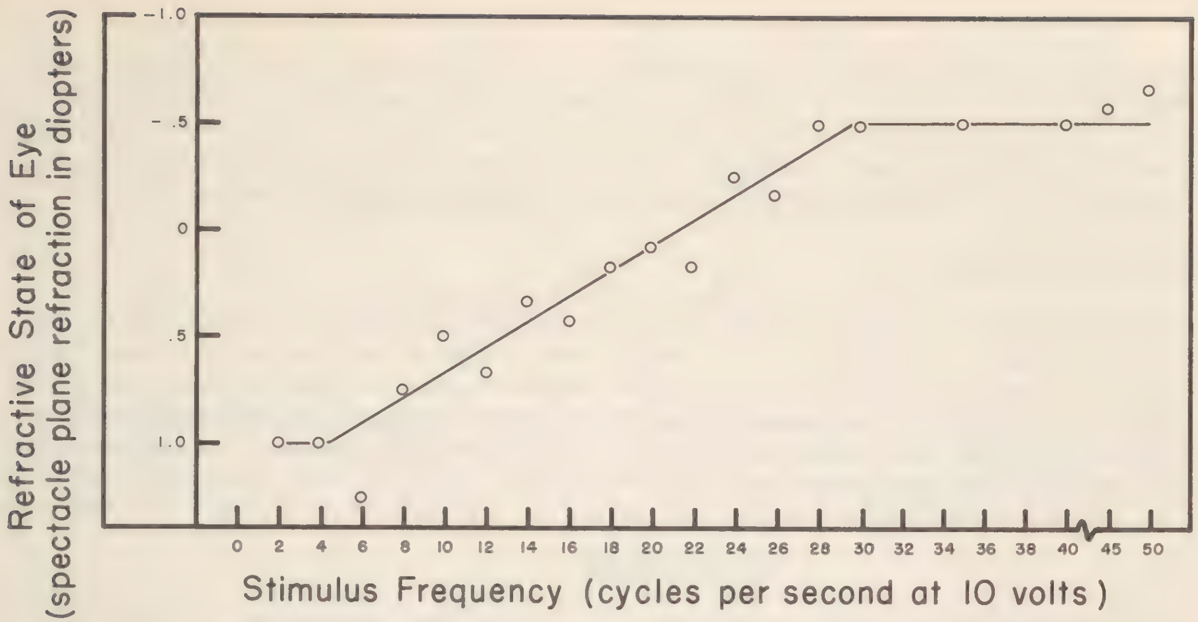

Figure 2

The stimulus frequency curve (Figure 2) of the old cat has no obvious characteristics that distinguish it from similar curves of younger cats. The lower frequency threshold at 4 cycles per second does not appear to differ in the two sets of data and the upper frequency threshold, considering the possible unreliability of comparing absolute voltages from one preparation to another, seems to be within normal limits for young cats. The amplitude of accommodation is 1.5 D. which is low when compared to that shown in the curves for young cats.

The only important feature of the data from the old cat compared to that of the young cats appears to be a reduction in the amplitude of accommodation. The next and obvious question is how significant is this apparent reduction? In other words, is it likely that the difference in accommodation in the two experiments is due to experimental variation rather than being a real, significant difference?

Significance of the Apparently Reduced Amplitude

The original raw data from young cats were studied with a view to determining the limits of the amplitude of accommodation. Where different curves obtained from the same eye did not agree as to amplitude, the highest value was chosen on the assumption that it was probably closer to the real amplitude. This seems reasonable since poor electrode placement, injury from the surgery or the stimulation, or fatigue, may cause a decrease in the apparent amplitude. Seventeen sets of data showed a mean accommodative amplitude of 1.9 D. with a standard deviation of ± 0.4 D. The range was from 1.2 to 2.6 D. Using the same criterion for the amplitude on the curves of the aged cat, the 1.5 value would be used for comparison. This value is only one standard deviation from the mean amplitude for young cats, and therefore cannot be considered significantly low.

Comparison of Amplitude in Cats and Man

It is generally believed that the average man's amplitude of accommodation is reduced to 1 diopter or less by the age of 60 and does not change after that.* This is less than one-tenth the amplitude of youth. If a parallel phenomenon took place in cats, one would expect to find 0.2 D. or less of amplitude in a cat which had the equivalent age of a 60 year-old human being.

* These data are obtained by using stimulus values (subjective blur) rather than response values (as obtained by stigmatoscopy) which are more valid. Unpublished preliminary results of Hamasaki, Ong and Marg indicate that the accommodative amplitude is generally zero after the age of 52.

What then is the equivalent age of a 15-year-old cat? There appears to be no experimental evidence that would indicate this relationship. Veterinary clinical experience indicates that one year of a cat's life is equal to five or six years of a man's life.[2] On this basis our aged cat would have an age equivalent to a man 75 to 90 years! Hence little, if any, accommodation would be expected if the course of man's amplitude were paralleled by that of the cat.

Summary and Conclusions

The accommodative response of the eye of a 15-year-old cat to electrical stimulation of the ciliary ganglion was measured. The data were compared with those of a previous similar study on young cats. The accommodative amplitude of the aged cat was lower than that of the average young cat, but not significantly so. When compared with the decrease of accommodative amplitude with age in man (which gives rise to presbyopia) it is clear that the aged cat exhibited no similar phenomenon.

REFERENCES

1. Marg, Elwin; Reeves, J.L., and Wendt, W., Am. J. Opt., Mar. 1954, 31, 127-136.

2. Schlotthauer, C.F., D.V.M., Mayo Foundation, personal communication.

Discussion

Dr. Bach inquired of Dr. Marg as to what he did about synthetic components which passed through the ciliary ganglion. Dr. Bach went on to say that the synthetic system has a tremendous effect on accommodation in the cat though this is not so true in the human. He also inquired whether in decerebrating the preparation the plane of decerebration passed through the third nerve nucleus and to the left of some of the ciliary muscle in a different state than when Dr. Marg's experiment was started. Dr. Bach remarked that with reference to translating these results to the human, the range of amplitude of accommodation in the human is affected by factors other than peripheral nerve stimulation. The accommodative movement, that is, the degree of contraction from muscles stimulating peripheral nerves is way out of bounds with what can be obtained from impulses of central nervous origin.

Dr. Marg in reply stated that he was not aware that any work had been done with regard to the stimulation of the ciliary muscle in the human giving larger amplitudes.

Dr. Bach felt that one would get a much stronger contraction of muscles when the peripheral nerve in the muscle was stimulated than when the impulse is originated in the central nervous system. He wondered how justifiable it was to translate accommodative changes in the cat with the results of stimulation of the peripheral nerve—what happens to accommodate the changes in the human.

Dr. Marg stated there were many other criticisms along this same line; that in any electrophysiological experimentation of this sort there are many tacit assumptions. This was really only the first step and the best that could be done under the circumstances. With regard to the sympathetic nervous system the sympathetic nerves, at least in the cat, do not go through the ciliary ganglion.

Dr. Marg did not think that they were stimulated and even if they were the work of Morgan Ohmstead and others has shown that the sympathetic response is about 1/10th of that of the in parasympathetic response. This was not a serious error. He stated that they tried to decerebrate between the superior and inferior colliculi but they were not sure just how close they came to the third nerve center. In one experiment the nerve to the ciliary ganglion was actually severed and there seemed to be no difference in the response.

REPORT OF 200 PARTIALLY BLIND PATIENTS EXAMINED FOR SUBNORMAL VISION LENSES

Dr. Gerald Fonda
The Ophthalmological Foundation, New York, N.Y.

Two hundred patients were examined for subnormal vision lenses at the Lighthouse (The New York Association for the Blind). Lenses were prescribed for 101 patients, all of whom were later interviewed to decide whether the lenses were beneficial to them. The examiner concluded that 60 patients were rehabilitated to an acceptable degree.

Table 1

Number of patients examined	200
Number of patients for whom lenses were prescribed	101
Number of patients for whom lenses were successful	60

The results of this project showed two significant things:

1. A correction for lenses seemed to make a worthwhile improvement in 50% of the patients examined.

2. Of those for whom lenses were prescribed 60% were judged to be successful by the standards of both the examiner and the patient.

The type of ocular pathology chiefly responsible for the subnormal vision in those cases in which lenses were prescribed were as follows:

Table 2

TYPES AND INCIDENCE OF
OCULAR PATHOLOGY CAUSING SUBNORMAL VISION

Optic atrophy	18
Corneal opacities	14
Glaucoma	13
Post-operative aphakia for congenital cataracts	12
Albinism	9
Macular degeneration	6
Myopic degeneration	6
Retinitis pigmentosa	5
Chorio-retinitis	4
Cataracts	4
Diabetic retinopathy	2
Keratoconus	2
Miscellaneous	6

This classification as presented is greatly oversimplified because many patients presented themselves with multiple pathology, e.g., corneal opacities, cataracts and glaucoma.

Some types of pathology impressed the examiner as offering a more favorable prognosis than others. Albinism seemed to be the most promising, whereas diabetic retinipathy, retinitis pigmentosa and glaucoma the least promising. However, the motivation and intelligence of the patients were by far the most important determining factors for a successful case.

The type of lenses prescribed were classified as regular lenses, simple magnifying lenses, doublet magnifying lenses and contact lenses. The vision of twenty-four patients was improved by regular lens correction; e.g., an albino who was wearing no glasses was greatly benefited by the following correction: O.D. -8.50 sph. +1.00 ax 90, O.S. -11 sph. +1.75 ax 90. There were a few aphakic patients examined who had been wearing no correction, consequently they appreciated the usual strong plus correction. These were groups of patients who only required a thorough refraction.

Fifty-four patients were given prescriptions for simple magnifying lenses. These can be considered simple microscopic lenses. These corrections ranged from +8.00 sph. to +30 sph. Many of the strong plus corrections were given in the form of bifocals when the distant correction improved the distant vision. Bifocals with +8 additions were commonly prescribed. The highest add in a bifocal was a +12 addition and this was a notable success.

Half-eye magnifying glasses proved most useful for patients requiring no significant distant correction.

Doublet magnifiers were prescribed for nineteen patients. The powers ranged from 8x magnification to 20x magnification. The high percentage of favorable results were impressive with 8x and 12x magnification.

Contact lenses were fitted to five patients. The contact lenses were prescribed by Dr. Allan Rossby of New York City who has been actively engaged in this field for the past 12 years.

No telescopic lenses were prescribed in this series of cases. The fact that no telescopic spectacles were prescribed may be as startling to you as it was to the examiner. A greater demand for telescopic lenses had been anticipated due to the prevalence of television. The majority of patients with subnormal vision enjoyed television and could look at it for hours by sitting at distances from one to three feet from the screen. Those who owned telescopic lenses preferred to sit closer to the screen and not wear the lenses. The examiner believed there were no patients in this group whose near vision would be benefited more by telescopic lenses than by a simple magnifying lens. However, one patient, a shoemaker, was examined who was wearing telescopic lenses at his work. In such a case no other magnifying device would supplant the telescopic lenses because a maximum working distance is essential for this trade.

It is instructive to note that regular lenses and simple magnifying lenses were prescribed in 77% of the cases.

Table 3

Type of Lenses	No. Prescribed	No. Successful	
Regular	24	10	(42%)
Magnification	53	32	(60%)
Doublet	19	14	(74%)
Contact	5	4	(80%)
Telescopic	0	-	

Table 4

DEGREE OF VISUAL DEFECT, INCIDENCE AND PERCENTAGE SUCCESSFULLY CORRECTED

Range of Visual Acuity	No.	No. Successfully Corrected	
1/200	1	-	
3/200 - 10/200	40	28	(70%)
11/200 - 20/200	28	18	(64%)
20/180 - 20/100	22	13	(59%)
20/80 - 20/50	7	1	(14%)
20/40 - 20/20	2	-	

The above chart records the degree of visual defect encountered in this project as well as the number in each group and the incidence of successful cases. The chart shows that 68% of the patients having subnormal vision seeking correction have a visual acuity of 20/20 and less. Sixty-seven per cent of this group were successfully corrected. The two patients whose vision ranged between 20/40 and 20/20 suffered from advanced chronic simple glaucoma with markedly constricted visual fields.

RESULTS:

1. Of 200 partially blind patients examined, the examiner believes that 101 could be sufficiently rehabilitated by subnormal vision lenses.

2. Of the 101 patients for whom lenses were prescribed, 60 were judged successful by the standards of both the examiner and the patient.

3. The incidence of the ocular pathology responsible for subnormal vision is tabulated.

4. The type of lenses prescribed, the number of each kind, and percentage of successful results are tabulated.

5. Degree of visual defect, incidence and percentage of successfully corrected cases are recorded.

6. Seventy-seven of all the subnormal vision cases were corrected by regular or simple magnification lenses.

7. The need for telescopic lenses was found to be very small, especially for distance.

8. Seventy-four per cent of success was experienced with doublet magnifying lenses.

9. Eighty per cent success was experienced with contact lenses.

THRESHOLD SENSITIVITY TO LIGHT MEASURED WITH AN EXTRANEOUS ULTRAVIOLET SOURCE IN THE VISUAL FIELD*

John C. Ogilvie and J. Eugene Ryan**
Defence Research Medical Laboratories
Toronto, Ontario, Canada

ABSTRACT

Light thresholds of normal and aphakic subjects, and subjects with implanted synthetic lenses, were measured under conditions of darkness and with extraneous violet (405 millimicrons) and ultraviolet (365 millimicrons) sources of equal apparent brightness in the visual field. It was found that the ultraviolet source caused a greater increase in the threshold of the normal eye than did the violet source. The additional increase could not be attributed to stray light, nor to constriction of the pupil. From the results obtained with subjects who had synthetic lenses, it was concluded that fluorescence of the lens of the normal eye would account for the additional increase in threshold produced by the ultraviolet source.

INTRODUCTION

Exposure of the eye to an ultraviolet source, causes fluorescence of the ocular media, the major source of fluorescence being the lens.[1] There is little information on the effects of fluorescence of the ocular media on scotopic function.

Keil[2] reported in a wartime study that the presence of a black light source in the visual field reduced sensitivity to light by one log unit. He attributed this to visible radiation from the source and fluorescence of the ocular media. Since controls were not employed nor was an emission spectrum of the source available, the relative importance of the factors Keil suggested cannot be gauged, nor can the possibility of other factors be eliminated.

To determine the separate effects of visible radiation and fluorescence, it is necessary to use a narrow wave band in the ultraviolet and for comparison a source of longer wavelength which does not excite fluorescence. In the three experiments described here, the light threshold was determined under absolute conditions, and also in the presence of sources of ultraviolet and violet radiation, respectively. First, the light threshold was measured during exposure to ultraviolet and to violet sources of equal brightness. The second experiment was undertaken to define the role of pupillary constriction. In the third, aphakics and subjects with implanted synthetic lenses were tested in an attempt to answer questions raised by the first two experiments.

APPARATUS

Monocular light thresholds were determined with a Hecht-Shlaer adaptometer.[3] The light stimulus was a 3° circular violet field, appearing 7° nasally, flashed for 1/5 second. The source of ultraviolet radiation was a 2-watt mercury vapor lamp of the type used to illuminate fluorescent instrument panels in aircraft (RCAF Part No. B-4235). Although the lamp housing includes a filter, a considerable amount of radiation above 400 millimicrons is emitted. In order to obtain a narrow band centered at 365 millimicrons two further

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*Defence Research Medical Laboratories Report No. 8-1, Project No. D77-94-20-12 (H.R. No. 84).

**Assisted by R. F. Cowan and E. I. Querengesser, Dept. of Ophthalmology, University of Toronto.

filters were mounted on the housing, a Bausch & Lomb 365 millimicron interference filter and a Corning filter #5840. The source of violet light was a 6-volt tungsten lamp in a similar housing with a 405 millimicron interference filter and a Corning filter #5113, which provided a narrow band of emission centered at 405 millimicrons.

The radiant intensities of the two sources were measured at various wavelengths by means of a monochromator with a photomultiplier tube and amplifier system. The radiant intensity of the violet source at its peak wavelength of 405 millimicrons, and at the highest brightness used, was 4.8 per cent of the radiant intensity of the ultraviolet source at its peak wavelength of 365 millimicrons. The intensity of the ultraviolet source had fallen, at 380 millimicrons, to 3.8 per cent of its maximum and at 405 millimicrons to less than 0.2 per cent of its maximum.

The sources were placed in the body of the adaptometer, 13^{o} below the test field; they provided a diffusely bright rectangle subtending $5^{o} \times 9^{o}$ at the eye.

EXPERIMENT I
The Absolute Threshold

Procedure

Thresholds were measured by the method of limits (five ascending and five descending readings) on eight subjects drawn from the staff of these laboratories. For each subject a control threshold was determined, then a threshold during exposure to the ultraviolet source, and finally a threshold during exposure to the violet source. Before the last threshold measurement was taken, the violet source was matched foveally with the ultraviolet in apparent brightness. Since it was difficult to expose the eye to both simultaneously, the violet test field of the adaptometer was used in an intermediate step. The latter was equated in brightness to the ultraviolet source. The ultraviolet source was replaced by the violet source which was then equated to the violet test field. This method for matching is necessarily crude because there are color differences, but the small variation in the repeated measurements on the three subjects, J.O., C.B., and M.H., shown in the last column of Table I, demonstrates its adequacy.

Results

The thresholds obtained under normal conditions and during exposure to the ultraviolet and violet sources are shown in Table I. The presence of ultraviolet radiation increases the threshold by at least 0.7 log unit and in most cases by well over 1.0 log unit. The thresholds are all at least 0.5 log unit higher than those measured in the presence of the violet source. Since the two sources were equated in brightness by each subject they should have raised the thresholds equally if they were simply sources of stray light interfering with the test patch on the retina. However, the difference in effect might be due to constriction of the pupil, fluorescence of the ocular media, or the action of the ultraviolet radiation on the retina.

EXPERIMENT II
The Size of the Pupil

Procedure

Four of the subjects in Experiment I, after having undergone the testing procedure as described, were kept in a state of dark adaptation and their eyes photographed. A Robot 35 mm. camera and a Portra No. 3 lens attachment were used with a General Radio Company 1530A Microflash, which gives a flash of 2 microseconds. It has been shown by Fry

and Allen[4] that the fully dilated pupil will redilate to its full extent 30 seconds after a brief flash. This was checked and confirmed. All photographs were taken at least one minute apart.

Four control photographs were taken of the normal dark-adapted pupil, then four with the ultraviolet lamp in the same position relative to the eye as it had been in the adaptometer. Four more photographs were taken with the violet source in the same position, and finally two photographs under normal conditions.

As an additional approach the right pupil was dilated with four drops of a 10 per cent solution of neosynephrine. When the pupil was fully dilated, three thresholds were taken. As a check on the effectiveness of the artificial dilation of the pupil, photographs of the dilated pupil were taken under normal conditions and during exposure to the ultraviolet source. The ultraviolet source did produce a slight constriction of the dilated pupils but in no case did it reduce their size to that of the normal dark-adapted pupil.

Results

The averages of pupil diameters measured on the photographs are shown in Table II. The pupil is constricted by both sources, the ultraviolet source being more effective. In no case was the pupillary area reduced by the ultraviolet radiation to less than one-half of its original area which is far short of the constriction required to account for the increased effect of the ultraviolet radiation.

Table III gives the thresholds of five subjects obtained with normal and dilated pupils. When pupil size was controlled by artificial dilation, the same differential effect of the ultraviolet and violet sources upon the threshold persisted.

Table I

Light Thresholds under Absolute Conditions and during Exposure to Ultraviolet and Violet Radiation

	Thresholds[1] - log $\mu\mu$L			Apparent Brightness
Subject	Absolute	Violet	Ultraviolet	of Sources - log $\mu\mu$L
J.O.	3.1	3.4	4.3	7.0
	2.9	3.3	3.9	7.0
	2.9	3.5	4.1	7.2
J.R.	2.8	2.9	4.0	6.4
C.B.	2.8	3.0	4.0	6.6
	2.7	3.0	4.2	6.6
	3.0	3.2	4.2	6.5
M.H.	2.9	2.9	3.6	5.6
	2.7	2.8	3.6	5.6
D.M.	2.6	3.2	4.0	6.8
E.Q.	2.6	3.3	3.8	6.4
R.B.	2.6	3.5	4.1	6.0
B.Q.	2.6	2.7	3.8	6.2

[1] Each threshold is the mean of ten readings.

EXPERIMENT III
Fluorescence of the Ocular Media

Fluorescence of the ocular media may be a factor in the increase in absolute threshold due to ultraviolet radiation. According to Klang,[1] the only part of the eye that fluoresces to any great extent is the lens. Therefore the effect of fluorescence will be practically eliminated in aphakic eyes and eyes with implanted synthetic lenses, i.e., Ridley lenticular implants.[5]

Procedure

Two subjects who had Ridley lenticular implants and five aphakics were tested in Experiment I. The synthetic lenses are made of acrylic plastic. It does not fluoresce under exposure to ultraviolet radiation and has a transmittance of 70-80 per cent at 365 millimicrons.

That the ultraviolet source appeared much brighter to both groups of subjects than to normal subjects is demonstrated by the increase in the violet source to bring about a match in apparent brightness. Additional measurements were made on the subjects with synthetic lenses, with the ultraviolet source reduced in brightness so that it might appear at the same level as it did to the normal eye.

With two of the aphakics a +12D lens was inserted in the adaptometer eyepiece to compensate for their large refractive error. The transmittance at the center of this lens was found to be about 70 per cent at 365 millimicrons.

Results

The thresholds for the subjects with synthetic lenses are shown in Table IV. Both violet and ultraviolet sources produced equivalent increases in the threshold at low brightness. At high brightness, the increased effect of the ultraviolet persisted for subject G. The results for the aphakics are given in Table V. In all cases the ultraviolet source increased the threshold more than did the violet.

Table II

The Diameter of the Pupil under Absolute Conditions and during Exposure to the Ultraviolet and Violet Sources

		Pupil Diameter - mm		
Subject	Eye	Absolute[1]	Violet[2]	Ultraviolet[2]
J.O.	R	5.7	5.5	4.6
	L	5.6	5.3	4.1
J.R.	R	7.6	6.8	5.8
	L	6.9	6.2	5.0
C.B.	R	6.7	6.3	5.1
	L	7.0	6.4	5.3
E.Q.	R	8.3	7.7	7.5
	L	8.1	7.8	7.4

[1] Each value is the mean of 6 measurements

[2] Each value is the mean of 4 measurements

Table III

Light Thresholds with Normal and Dilated Pupil under Absolute Conditions and during Exposure to Ultraviolet and Violet Radiation

	Thresholds - log $\mu\mu$L					
	Normal			Dilated		
Subject	Absolute	Violet	Ultraviolet	Absolute	Violet	Ultraviolet
J.O.	2.9	3.5	4.1	2.9	3.5	4.1
J.R.	2.8	2.9	4.0	2.8	3.0	4.0
C.B.	2.7	3.0	4.2	2.7	2.9	4.1
E.Q.	2.6	3.3	3.8	2.8	3.4	4.0
R.B.	2.6	3.5	4.1	2.6	3.5	4.0

Table IV

Light Thresholds of Subjects with a Synthetic Lens in One Eye under Absolute Conditions and during Exposure to Ultraviolet and Violet Radiation

		Thresholds - log $\mu\mu$L			
Subject	Eye	Absolute	Violet	Ultraviolet	Apparent Brightness of Sources - log $\mu\mu$L
K	Normal	2.7	2.8	3.5	5.1
	Synthetic lens	3.0	5.3 3.3	5.4 3.2	6.8 5.3
G	Normal	3.0	3.1	3.9	5.6
	Synthetic lens	4.4	6.0 4.7	6.8 4.6	8.2 6.4

Table V

Light Thresholds of Aphakic Subjects under Absolute Conditions and during Exposure to Ultraviolet and Violet Radiation

Subjects	Thresholds - log $\mu\mu$L Absolute	Violet	Ultraviolet	Apparent Brightness of Sources - log $\mu\mu$L
M	4.0	4.9	5.6	8.0
M (with +12D correction)	3.4	4.5	5.4	
C	4.3	5.8	6.3	8.6
C (with +12D correction)	4.6	5.4	5.7	
S	4.6	5.1	5.8	8.6
MC	3.6		6.6	8.1
T	3.7		6.3	

DISCUSSION AND CONCLUSIONS

The possibility that the color of the test flash was a factor in this experiment was investigated. It was found the the same relative increase was obtained when the test flash was green, or blue, rather than violet.

The violet source was used in order to control the effects produced by the visible patch of ultraviolet on the test field. To control the effect of stray light, the brightness of the violet source should match the ultraviolet source. This was the method used since the fluorescence present during the matching procedure would add an equal increment to each source. In order to control any neural interaction, however, brightness of the violet source should equal that of the ultraviolet plus the increment due to fluorescence. Since tests failed to reveal any perceptible difference in the brightness of the violet source when fluorescence was produced in the ocular media, it is assumed that the increment is negligible.

The matching of the two sources in apparent brightness was done foveally. Since their effects on a peripheral test field were being investigated, foveal matching may seem inappropriate. However, the relative differences in sensitivity to 365 and 405 millimicrons of the rods and cones are approximately the same.[6]

Since exposure to the two sources might have effect on subsequent thresholds, the time to return to threshold was investigated. Exposure to the ultraviolet source had no measurable effect. It was found that within one minute after the termination of a three minute exposure to the ultraviolet source, subjects were responding to stimulus intensities within the range of those used for determining absolute threshold.

During exposure to ultraviolet radiation the light threshold was increased by one log unit. Neither stray light nor interaction could account for this increase since it was not found in the presence of a violet source of equal apparent brightness. The differential effect of the two radiations upon the light threshold could not be accounted for by constriction of the pupil.

The results obtained with subjects who had synthetic lenses indicated that the additional increase in threshold during exposure to the ultraviolet source is caused by fluorescence of the lens. This was demonstrated when the brightness of the ultraviolet source was made equivalent to its brightness when observed by the normal eye. Results from the aphakics would seem to disagree with the above conclusions. However, it should be noted that with them, the ultraviolet source appeared very bright and under these conditions an additional increase was obtained with subject G, who had a synthetic lens. This would seem to indicate that at low brightness any fluorescence produced by the ultraviolet sources outside of the lens was negligible but that it became an important factor at high brightness.

Subjects with synthetic lenses were asked to report the appearance of the sources to each eye. With their normal eye exposed to the ultraviolet source, the visual field appeared hazy, as it did to normal subjects. However, when the eye with the synthetic lens was used, there still remained a trace of haze. In the absence of the normal lens the haze must be due to fluorescence of other parts of the eye, and according to Klang,[1] the cornea, and aqueous humor do fluoresce. While the fluorescence of these parts of the eye is negligible in comparison with that of the lens, in the absence of the latter, they may play a role in the increase of the threshold. In addition, the aphakic subjects were older people, all but one being over sixty years of age, and it is possible that fluorescence of the ocular media, other than the lens, may increase with age as it does with the lens itself.

It may be concluded that the increase in light threshold during exposure to ultraviolet radiation of low intensity is partly due to stray light but mostly to fluorescence of the lens.

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Discussion

Dr. Knoll asked if the wavelength of the violet light was 405 millimicrons.

Mr. Ogilvie answered in the affirmative.

Dr. Knoll wondered whether the author would care to describe a little more carefully the comparison of the kinds of brightness of the distortion, with reference as to whether it was foveally or exfoveally.

Mr. Ogilvie felt it reasonable to assume that the foveal match could hold on the periphery.

Dr. Knoll then asked if Mr. Ogilvie would say that the foveal and exfoveal was the same in this region.

Mr. Ogilvie asnwered that it appeared so in these curves.

Dr. Crozier mentioned that Dr. Wolf carried through an experiment essentially like this with similar results, but using a higher intensity of filtered ultraviolet obtaining a larger shift in threshold. The majority of the existing experiments on the alleged effect of ultraviolet light on vision are defective in the sense that it would be desirable to have. Dr. Crozier continued by saying that apparently we do have experiments in which filtered near-ultraviolet is added to or introduced into a situation in which other kinds of light are operating in the determination of thresholds. He also commented on the fact that literature of this topic has been confused by very interesting errors of experimentation as in the case of a paper by Dr. Wald communicated several years ago. Dr. Crozier felt one could well be excused for having fallen into the error in which Dr. Wald did fall, namely, of comparing alternately, thresholds during dark adaptation in two eyes, one of which had been exposed to ultraviolet. Under those circumstances, if one determines thresholds alternately in the two eyes, the curves will run together whereas, if determined independently, they would not. The differences are small but pertinent.

CDR Farnsworth, because of the possible military importance of it, commented on an experiment that the Navy has been conducting for some years along similar lines; not examining as many conditions as the Canadians but concentrating on one principle which he felt may or may not be true but that it is a method of investigation. He further commented that it was questionable if a moderate amount of ultraviolet produces a disputable effect as was found in Wolsworth. His theory was to pour a tremendous amount of ultraviolet into the eye and an appreciable and easily measured effect should be produced. The results of this method were that there did not appear to be specific effects of ultraviolet on the retina, and any decrement to sensitivity was apparently the result of the fluorescing component.

OXYGEN EFFECTS ON PERIPHERAL VISUAL THRESHOLDS*

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In earlier communications to this Committee I have dealt briefly with effects of O_2 concentration in atmosphere inspired on 'absolute' visual thresholds, particularly at fovea. Data on 'incremental' thresholds at fovea are also available in quantity. The present report concerns incremental intensive thresholds in retinal periphery (10^0 temporal). O_2 mixtures were administered by mask. Conditions of three types were used: '100'% O_2, Air, 9% O_2, in each case with 0.4% CO_2 and saturating H_2O vapour. Stabilized respiration and visual excitability were initially established. Data were obtained by use of seeing-frequency procedures, with semi-automatic recording, at several presentation times, and over a considerable variety of wavelength situations. The results unequivocally reveal peculiarities of O_2-effects on uniocular visual thresholds, as function of λ. They permit quantitative comparisons of 'cone' peripheral properties with those at fovea. They help to illuminate "mesopic" visual peculiarities, and they open roads to important, novel advances in visual theory.

The incremental threshold conditions for the data of this note are: an adapting field 15^0 square, of λ_1, continuously present; a test field 0.5^0 square at retina; both fields centered 10^0 on the temporal side of one retina (L or R in different observers). For different light-adapting levels of $\underline{I}_1$, of λ_1, seeing-frequency $\psi(\underline{S})$ data were obtained for λ_2 (including the case $\lambda_1 \equiv \lambda_2$). From this information, including that for $\underline{I}_1 = O$ (dark-adaptation) at the three levels of O_2 intake used, information here partially summarized was computed.

For test-lights in retinal periphery, as function of light-adapting $\underline{I}_1$, it is very clear that for low-adapting intensities of λ_1 the rather canonical effect of increasing $[O_2]$, under whatever conditions of λ_1, λ_2, is obtained. In the examples cited, a tungsten 'white' λ_2 of color temperature 2650^0, is used to test light-adaptation by 'white', blue, yellow-green, and far red λ_1. The quantitative properties of the component sections of the curves exhibited are consistent with other information, with other λ_1, λ_2 combinations investigated.

In the analysis of incremental threshold data, as obtained by $\psi(\underline{S})$ procedures, several parameters of excitability functions yield information: (a) the maximum excitability $(1/\Delta\underline{I}_{50})_{min.}$; (b) the median excitability $(\tau'_{\log \underline{I}_1})$ - the value of $\log \underline{I}_1$ (λ_1) which reduces maximum excitability by λ_2 to 1/2 its magnitude; and (c) $\sigma_{\log \underline{I}_1}$, the S.D. of $\log \underline{I}_1$ (λ_1), which measures the capacity of λ_1 to "mask", or 'adapt out' sensitivity to λ_2. These parameters have been estimated, by $\psi(\underline{S})$ procedures, for a variety of circumstances.

For the extra-foveal situation a complication is demonstrated. Historically, it has been shown that a species of complication in the foveal incremental contours, claimed by

*The investigation of which this note is one outgrowth has been supported in part by ONR Contract N5 ori-07642.

Stiles, is quite illusory. But for retinal regions outside the fovea another and more interesting type of complication is unexpectedly revealed.

In a sense, these results make it clear that there is physiologically a "mesopic" range of visual excitability. But it is also shown, I believe, that it is highly questionable to rely, for practical purposes, upon estimates of visual excitability in this range of light-adaptation.

Quantitative statements are provided by this body of data respecting a variety of additional problems, some of them incidental to the central inquiry. Among these are two I may cite: (a) To what extent are putative 'cone' properties in retinal periphery comparable to those at central fovea? and (b) Does 'red' light act "only" on peripheral 'cones'? The evidence is unequivocally no. The related matter of "red sensitization" is, with qualification as to the nature of the question, rejected.

Returning to the essential topic: in the "mesopic" region, for parafovea, there is (regarding the conditions of chromatic, λ_1, adaptation), less confusing only in part when $\underline{t}_{exp.}$ is altered, an apparently confused situation: the action of $[O_2]$ is uneven; at high levels of light-adaptation there is comparatively little difference, in most cases, between threshold ($\psi[\underline{S}]$) values at extreme values of $[O_2]$ inhaled. No simple statements of this sort tell at all adequately the meaning of the data available, because analytically the situation is in fact inevitably complex. A conclusion clear here for a long time is that with increasing intensities requisite for 'threshold' responses, however dictated (as by shorter presentation times, or higher levels of light-adaptation, or by use of other than mere "light" criterion with subdivided test patterns), the influence of $[O_2]$ inspired, at sea-level pressures, becomes less and less as $\underline{t}_{exp.}$ is decreased.

In addition to the further exemplification and testing of the duplex nature of the scotopic excitability contour it is notable that the far red lights really cannot be said to act only on "rod" units. There is no sign of sensitization by red light.

Discussion

Dr. Blackwell mentioned that the data that Dr. Crozier exhibited were for homochromatic white light in the periphery. He went on to ask whether or not Dr. Crozier had yet done the homochromatic white light or monochromatic light in the fovea.

Dr. Crozier replied in the affirmative.

Dr. Blackwell inquired whether he had found any kinks.

Dr. Crozier answered in the negative, though he had put forth a lot of energy in an attempt to understand what Mr. Styles had done because it was a difficult job to interpret this paper. Dr. Crozier stated he had done experiments of this sort in the fovea at two different exposure times with five experienced observers, but that he had never found kinks.

Dr. Blackwell then asked whether he had tried different optical levels.

Dr. Crozier said that it had been done two years ago but that he had not done barometer reporting since then.

DIFFERENCE-LIMENS FOR PHOTIC INTERMITTENCE

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INTRODUCTION

Mowbray and Gebhard[3] recently examined the temporal resolving power of the eye in a new way. Difference-limens (DL) for intermittent white light were studied in the range of 1 to 45 cps, and were shown always to be smaller than 0.8 cps (Fig. 1). When the DLs were integrated, the number of just noticeable differences (j.n.d.) reached the surprisingly large sum of 280. This appeared to be a very creditable performance for the eye. The present study extends the data on DLs for flicker. In the experiment previously reported, only 20 to 50 measurements per frequency for each of two Ss were obtained. Now, using two new Ss, the number of thresholds obtained has been increased to 150. The stimulus conditions and apparatus were exactly the same, so the results of the two experiments can be directly compared.

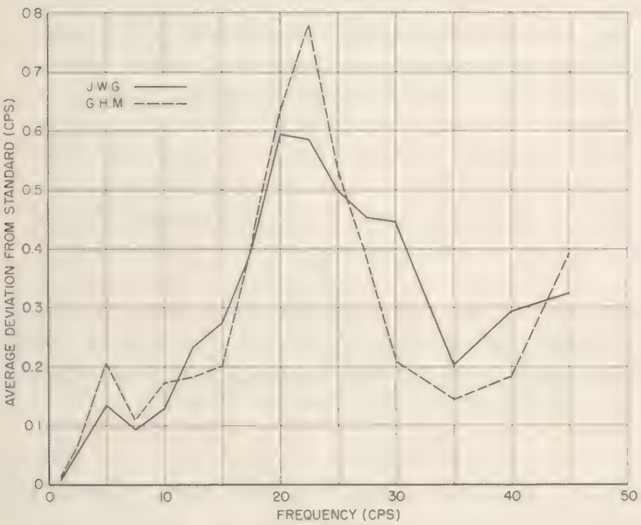

Figure 1. The A.D. of the thresholds as a function of frequency. Mowbray and Gebhard.[3]

METHOD

Apparatus. A Sylvania R1131C glow-modulator tube produced the light that was viewed binocularly on a 1° circular spot with a homogeneous luminance of 98 mL. The spot was centered in a white surround of 71° subtense held at 44 mL. The input to the flash tube was an electric square wave

$$\frac{D}{T} = 0.5$$

produced by two accurate variable-frequency generators. Since the response of the tube faithfully followed the input, the retinal illuminance was also a square wave. The two input channels were separately applied to the same flash tube by a switch controlled by S. One channel carried the standard frequency, the other the comparison. S adjusted the comparison frequency to match the standard by a linear Helipot, and the discrepancy between the two channels was measured by a Hewlett-Packard timer to an accuracy exceeding that of the flash generator.

Procedure. For each replication of the experiment, 16 frequencies were presented to two Ss in random order. At each frequency S made 5 measures at a sitting by the method of ascending and descending thresholds. He then alternated with the other S until each had 15 matches. There were 10 complete replications, resulting in 150 matches per frequency for

* This work was done under Contract NOrd-7386 between the Bureau of Ordnance, U.S. Navy and The Johns Hopkins University. The writers gratefully acknowledge the painstaking efforts of Mr. Michael Duffy and Miss Millie Borntrager who acted as Ss in the collection of these data.

each S and a total of 4800 thresholds for the entire experiment. The experimental design, therefore, permitted the data to be divided into as many as 10 equal parts.

TREATMENT OF DATA AND RESULTS

Normality of Threshold Data. The first subject of interest in this experiment was the distribution of the individual thresholds about each standard frequency. This was investigated by combining both Ss and all 10 replications. The normal probability distribution was fitted to each of the 16 frequency distributions, and the χ^2 test of goodness of fit was applied. The tests indicated the surprising fact that every one of these distributions was non-normal. The reason for the non-normality was determined by graphic investigation to be extreme leptokurtosis. An example of this is shown in Figure 2, where it can be seen that a larger proportion of thresholds than would be predicted by the normal distribution fall close to the standard frequency. There was no evidence at any frequency of statistically significant skewness.

Because the Ss were known to have been learning rapidly, it was felt that this could have caused leptokurtosis by introducing a few extreme errors early in the experiment and a large proportion of relatively small errors in the later stages. When the experiment was divided into two equal parts, and the second five replications were examined separately, this supposition was supported in that the leptokurtosis at some frequencies was reduced. Further analysis, therefore, was based entirely on the combined judgments of both Ss in the second half of the experiment. These samples of 150 measures per frequency were still leptokurtic, although at 11 of the 16 frequencies there was a probability ranging from 0.1 to 0.9 that the experimental sample had been drawn from a normal population. The remaining five frequencies of 1, 5, 30, 40 and 45 cps were still found to be inconsistent with the hypothesis of normality. A more valid hypothesis, therefore, is that all of these distributions are leptokurtic. This implies that the eye is able to do a better job of establishing relative thresholds than would be expected on the basis of the theory of random errors of measurement.

Effect of Practice. Since learning is an important factor in psychophysical experiments, the standard deviation (S.D.) of the individual measures was computed for each S as each replication was completed. It was noted that considerable improvement was taking place during the early replications. As the experiment progressed, the Ss gradually became less erratic and their thresholds became smaller.

At the completion of the experiment, all replications were combined for each S and the S.Ds. computed. These thresholds are plotted against frequency in Figure 3. The two curves approximate the pattern anticipated on the basis of data previously collected and shown in Figure 1. Nevertheless, the two Ss are seen to be inconsistent and in rather poor agreement in this total picture.

When the experiment is divided into two equal parts, however, we see in Figure 4 that the thresholds in the first half are very high. Both Ss are extremely variable, and their peaks and troughs fall at different frequencies. Figure 5, for the second half of the experiment, shows the thresholds to be much lower than in the first half. After much practice, the two Ss are seen to be more stable, and their agreement is good, except for an isolated peak at 12.5 cps.

The DL Function. When the two Ss are combined for the second half of the experiment, we have the reasonably stable presentation of the thresholds shown in Figure 6. While two peaks are seen at 12.5 cps and 30 cps, the 95% confidence intervals placed around the sample S.Ds. indicate that the population values are not at all well defined with the amount of data collected. Average deviations (A.D.) and quartile deviations have also been computed for the second half of the experiment and are plotted in Figure 6 to show the patterns of these alternative measures of threshold. For the stimulus conditions of both this and the previous experiments, a comparision of Figures 1 to 6 shows that the DL's rise sharply between one

and about 15 cps, reach a maximum at between 20 and 25 cps, fall somewhat in the region of 30 to 35 cps and finally rise again as the fusion point of about 50 cps is approached. The more highly practiced Ss of the second experiment produced lower thresholds in the middle range of frequencies but appear not to have altered the general shape of the function.

Integration of DLs. The next step was to determine the number of j.n.ds for the most stable part of the data. This involved the graphic integration of $\frac{1}{\Delta f}$, where Δf was the A.D. of the measures obtained at each frequency in the second half of the experiment. The number of j.n.ds between one and 45 cps is 375, a total considerably higher than the 280 reported earlier. In Figure 7, the accumulated j.n.ds are plotted against frequency.

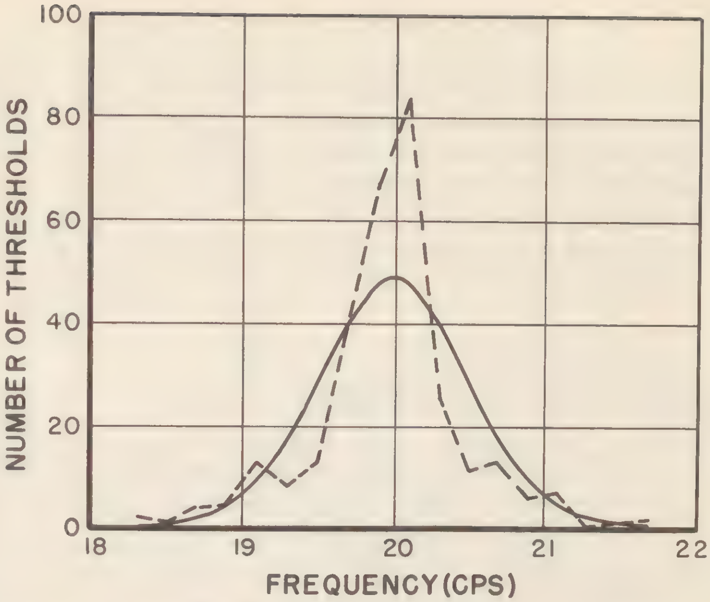

Figure 2. Frequency distribution of thresholds at 20 cps showing leptokurtosis. Subjects are combined for all 10 replications, and their data compared with a normal distribution based on a mean of 20 cps and a S.D. and N equal to those of the sample.

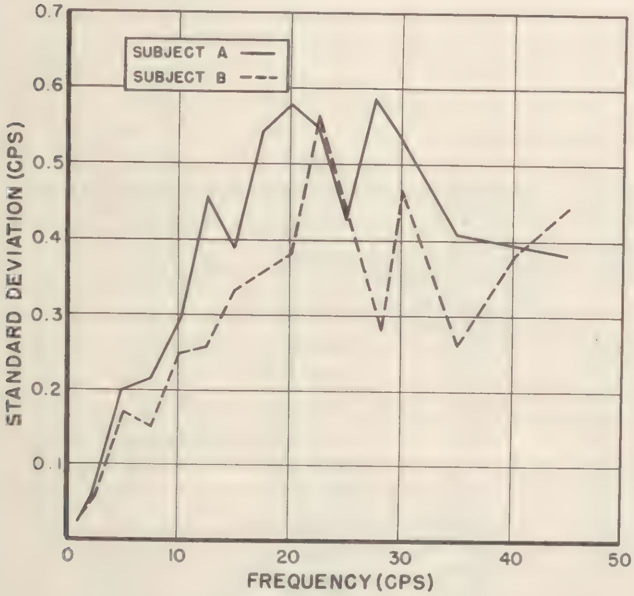

Figure 3. The S.D. of the thresholds as a function of frequency for all 10 replications.

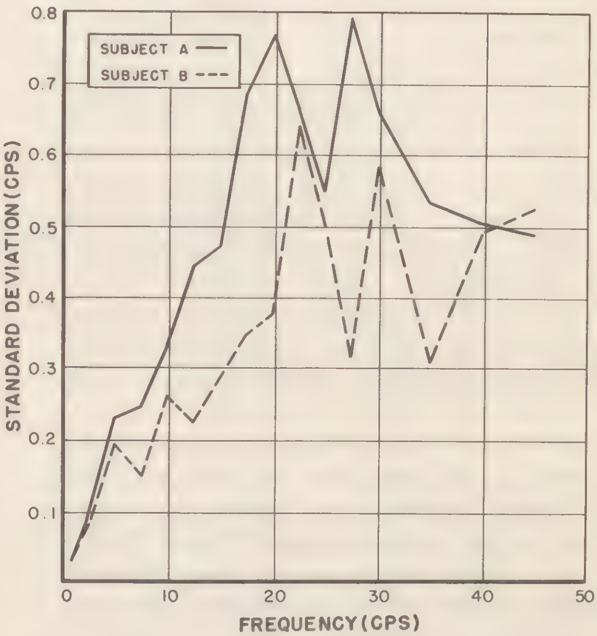

Figure 4. The S.D. of the thresholds as a function of frequency for the first 5 replications.

Summary of Results. The important findings of the second five replications of the experiment are brought together in Table I. The accuracy with which the standard frequency is measured is shown in column 3. It will be noted that the obtained frequencies differ on the average from the standard by never more than 0.09 cps, and 12 of the values are under 0.031 cps. In column 6, the relative DL, $\frac{\Delta f}{f}$, is shown. The range is from 0.005 to 0.024 and is somewhat smaller than was obtained in the first experiment. Column 7 shows the cumulated DLs of Figure 7.

DISCUSSION

The temporal resolving power of the eye has received little attention, except for the bearing that the critical flicker frequency has on this problem. The ear, however, is considered to be the time analyzer par excellence and, accordingly, has been extensively studied.[5]

Critical Flicker Frequency vs. Critical Flutter Frequency. Studies on the CFF do not reveal the eye as a strong competitor of the ear. The highest frequency at which interrupted white light still appears to flicker is only about 60 cps under optimum conditions. This frequency represents a period of 16 msec. On the other hand, the ear is able to discriminate interrupted white noise, or flutter as it has been termed by Miller and Taylor, at over 1000 cps.[2]

Difference-Limens. Another way of looking at the temporal acuity of the eye or ear is the DL method chosen for this experiment. The smallest increment in frequency that produces a j.n.d. in experience measures an important aspect of the temporal resolution of the eye or ear. The differential sensitivity to the frequency of a tone has been reported in many studies on pitch discrimination.[5] Recently, Miller and Taylor[2] measured DLs for flutter. Table II shows the relative DLs for pitch, flutter and flicker equated as well as possible by selecting from the available data.

Pitch is a fused, qualitatively unique experience and may be the stranger in the Table. Flutter and flicker are experienced as intermittence at low rates of interruption but tend to change qualitatively as the rate is increased. Flutter, for example, takes on a tonal character at about 40 cps, becomes noise differing in quality from steady noise at 250 cps and finally is indistinguishable from steady noise at about 2000 cps.[2] Flicker, too, passes through various phases from slowly alternating light and dark intervals at low frequencies to a sensation of fused brightness at about 60 cps[1]. To these qualitative difficulties in comparison are added two

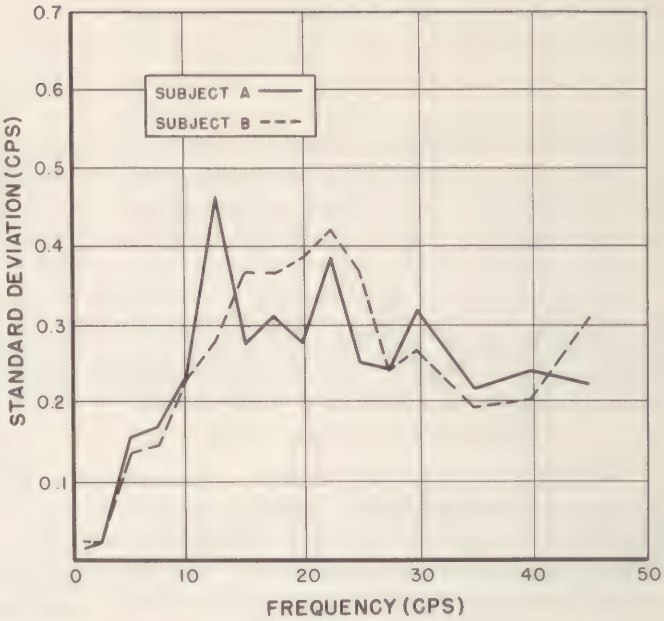

Figure 5. The S.D. of the thresholds as a function of frequency for the second 5 replications.

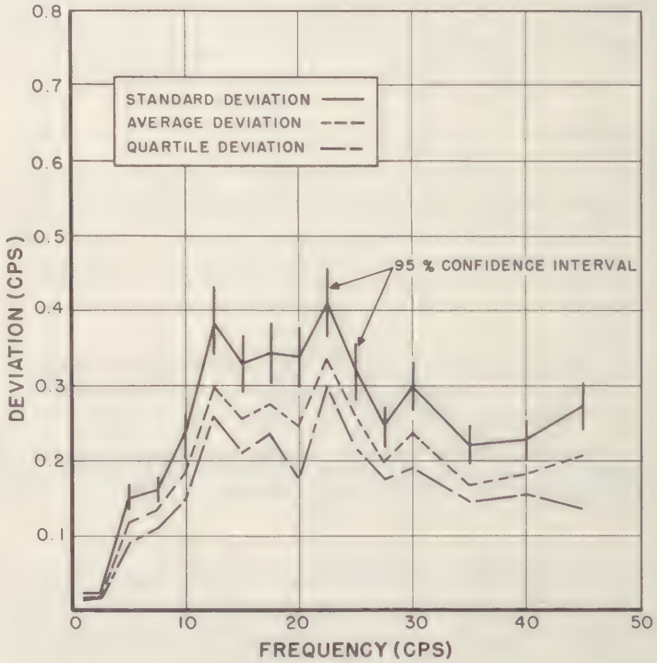

Figure 6. S.D., A.D. and quartile deviations of the thresholds as a function of frequency for the second 5 replications. Subjects are combined, and the 95% confidence interval is shown about the S.C.

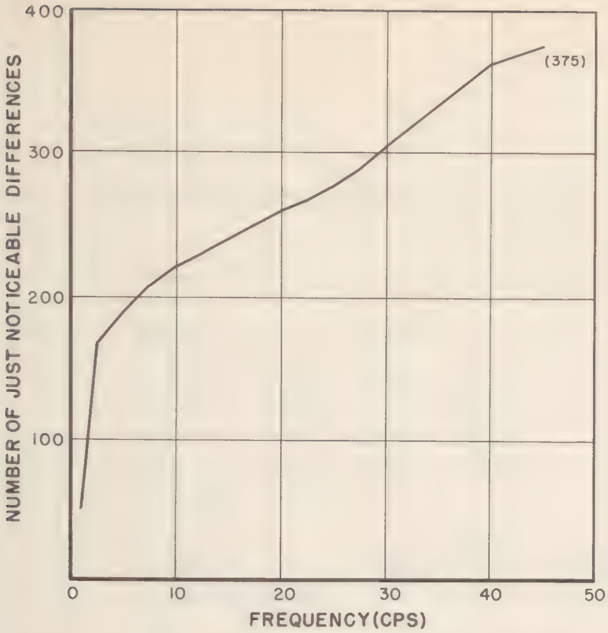

Figure 7. The number of j.n.ds as a function of frequency obtained by graphic integration of the DLs Subjects are combined for the second five replications.

others. First, there are only two frequencies where flutter and flicker overlap; and second, Miller and Taylor used a method of constant stimuli in collecting their data, whereas we used a method of average error. Whatever these differences may entail, it is noteworthy that the DLs for flicker are respectably small and that they hold their own when compared to their auditory cousins.

SUMMARY

DLs for visual intermittence were measured in the range of one to 45 cps. The S.Ds. vary from 0.02 to 0.41 cps, and the relative DLs computed from the A.D. are from 0.005 to 0.024. This surprising capacity of the eye to react to differences in intermittence results in 375 j.n.ds in a range of only 45 cps.

Table I

SUMMARY OF RESULTS FOR SECOND FIVE REPLICATIONS. BOTH Ss COMBINED.

Standard frequency (cps)	Mean measured frequency (cps)	Mean difference (cps)	S.D. (cps)	A.D. (cps)	$\frac{\Delta f}{f}$ computed from A.D.	Cumulative DLs
1	1.002	.002	.022	.015	.015	50
2.5	2.498	.002	.022	.017	.007	168
5	5.046	.046	.151	.118	.024	189
7.5	7.480	.020	.161	.132	.018	208
10	9.991	.009	.238	.184	.018	222
12.5	12.531	.031	.388	.299	.024	230
15	15.011	.011	.329	.254	.017	240
17.5	17.522	.022	.343	.275	.016	249
20	19.969	.031	.338	.246	.012	259
22.5	22.504	.004	.411	.340	.015	266
25	25.018	.018	.320	.261	.010	276
27.5	27.501	.001	.246	.197	.007	289
30	29.909	.091	.301	.238	.008	305
35	34.986	.014	.221	.166	.005	335
40	39.928	.072	.227	.181	.005	363
45	44.957	.043	.273	.206	.005	375

Table II

COMPARISON OF $\frac{\Delta f}{f}$ FOR PITCH, AUDITORY FLUTTER AND PHOTIC FLICKER.

Sensation[5] level (db)	Pitch[1] 50	Flutter[2] 50	100	Flicker[3] 85	Flicker[4] 85
Frequency (cps)					
20		.100	.100	.031	.012
40		.150	.075	.006	.005
62	.0351				
80		.162	.075		
120		.208	.083		
125	.0270				
160		.250	.094		
240		.333	.217		
250	.0099				
320		.459	.459		
500	.0042				
1000	.0036				
2000	.0019				
4000	.0023				
8000	.0025				
11,700	.0030				

[1] Shower and Biddulph (4).

[2] Miller and Taylor (2).

[3] Mowbray and Gebhard (3).

[4] The present experiment.

[5] In audition the sensation level is well understood to be the intensity level of a sound expressed in decibels (db) above the absolute threshold. The decibel scale is less widely used in reference to the intensity of sensations of brightness. The luminance of the flickering spot in these experiments was 98 mL or 85 db above the absolute threshold of vision. This corresponds to a moderately bright light in about the same sense that the 100 db noise in the flutter experiment is a moderately loud noise.

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Discussion:

Dr. Crozier inquired whether the flicker cycle was 50% light time.

Dr. Gebhard replied in the affirmative.

Dr. Crozier further inquired whether it would be possible with this same setup to use a 10% light time cycle, for example: the number of steps being increased by a factor of 10.

Dr. Gebhard remarked there is a means of changing the duty cycle or on-off time. It is possible to go down to something under a one-tenth duty cycle. A quick experiment had been done at a tenth comparing it with point 5 and point 9, but it was found that one could do somewhat better at point 1 than at point 5. More integrated DLs were obtainable by using point 1.

VISUAL DETECTION WHEN LOCATION IS NOT KNOWN EXACTLY

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This paper is concerned with the effect of prior knowledge of the position of a signal in the visual field on signal detection. In particular, the experimental data presented will involve comparison of detection of signals with position known exactly with the detection of signals known to be in either of two positions.

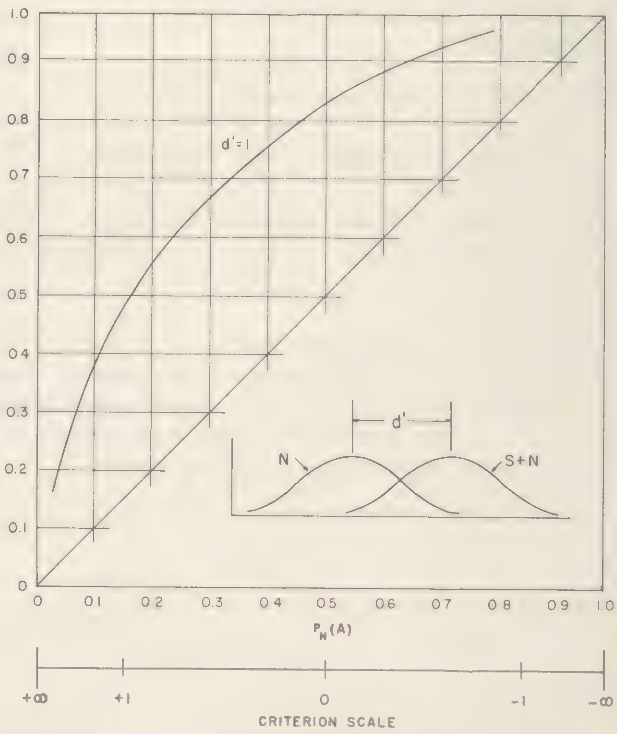
It is necessary to define the variable d' before proceeding with the theory and data analysis upon which this paper is based. The visual detection problem, in the opinion of the writer, is the problem of detecting signals in noise. If the problem is the detection of a signal of known parameters, and the judgment concerning signal existence is based on a measure of neural activity density at the output of the visual pathway, then there are two probability distributions of interest. These are shown in Figure 1. The ordinate is probability density, the abscissa is the value of the measurement. The distribution to the left represents the conditional probability density that, if noise alone is presented, the measure X will result. The distribution to the right is the conditional probability density that, if a signal is presented,the measure X will result.

The distance between the means of these distributions $M_S - M_n$ is a measure of the difference in neural activity density from noise and signal plus noise, and presumably depends on such physical variables as signal intensity. The variance of either of the distributions can be thought of as a sampling variable and presumably depends on such variables as signal duration or signal size, which determine sample size.

The parameter d' is a normalized variable

$$d' = \frac{M_S - M_n}{n} \qquad (1)$$

d' is thus a detectability index. For example, in the simple case where the observer is asked for a "yes" or "no" answer concerning the existence of a signal at a particular time, the problem is to determine from which of the two hypotheses the measure has come, i.e., noise alone or signal plus noise. d' is an index of the difference between the hypotheses.



$P_N(A)$ VS. $P_{SN}(A)$. THE CRITERION SCALE SHOWS THE CORRESPONDING CRITERIA EXPRESSED IN TERMS OF σ_N FROM M_N

Figure 1

Knowing d, it is possible to plot detection curves for signals associated with the d'. Such a curve is shown in Figure 1. This curve show the expected detection rate for signals which are transmitted as a function of false alarm rate when no signal is presented. Each point on the curve represents a different cut-off. For example, if we demand of the observer that he state whether or not a signal is present, then from this curve it can be seen that if he says the signal is present one-tenth of the time when it is not present, then he will say it is present thirty-eight per cent of the time that it actually is present. There is a curve such as this for each value of d'.

d', being a normalized variable, varies directly with $M_s - M_n$, and inversely with standard deviation. If standard deviation is held constant, d' is expected to increase with a change in signal intensity. If intensity is held constant, d' varies inversely with changes in standard deviation. For example, let us consider a case where for a given intensity, and given duration, d' has been determined for a signal of a given area. Now, let us double the area of the signal, keeping intensity and duration the same as before. Let us also assume that the observer can make optimum use of the information regarding area. Now he takes his measure of neural activity density over a sample twice as large as before. His estimates of the universe means are distributed with a variance inversely proportional to sample size, and standard deviation varies inversely as the square root of sample size. Thus, if we perform the above experiments, and the assumption regarding the observer's use of area information holds, then d' should increase as the square root of two.

Now, let us pursue the area problem a little further. Suppose that there is a minimum area possible for the observer to consider. The observer cannot make use of any area information regarding signals smaller in area than this minimum other than that they are at least as small as the minimum. He can no longer match his sample size to the signal size. Thus the standard deviation of the noise distribution remains constant for all areas smaller than this minimum. The neural activity density measured is an average of the density due to a signal and density due to noise, weighted proportionally to the respective sizes of the areas due to signal and due to noise. For example, if the area of the signal is 1/3 of the minimum observable area, then the measure is 1/3 of the density due to signal when the signal is the minimum observable area plus 2/3 of the density due to noise alone. Thus, as the area of the signal is decreased below the minimum observable area $M_s - M_n$ decreases proportionately. The variance, depending as it does on the area of observation, remains constant. Consequently, d' varies directly with areas less than the minimum observable area.

This leads to a prediction, that if intensity and duration are held constant, and area varied, a plot of log d' as a function of log area, should show a linear relation with slope 1.0 up to the minimum observation area; a linear relation with slope 1/2 for the areas where the observer can make use of the area information, and for all areas greater than a maximum possible observation area there should be no further change in d' with area. Figure 2 demonstrates data for one observer analyzed in this fashion. Slopes of 1.0 and 1/2 have been fitted by eye to the experimental points, and the point where these lines intersect is considered as an indication of the minimum observable area.

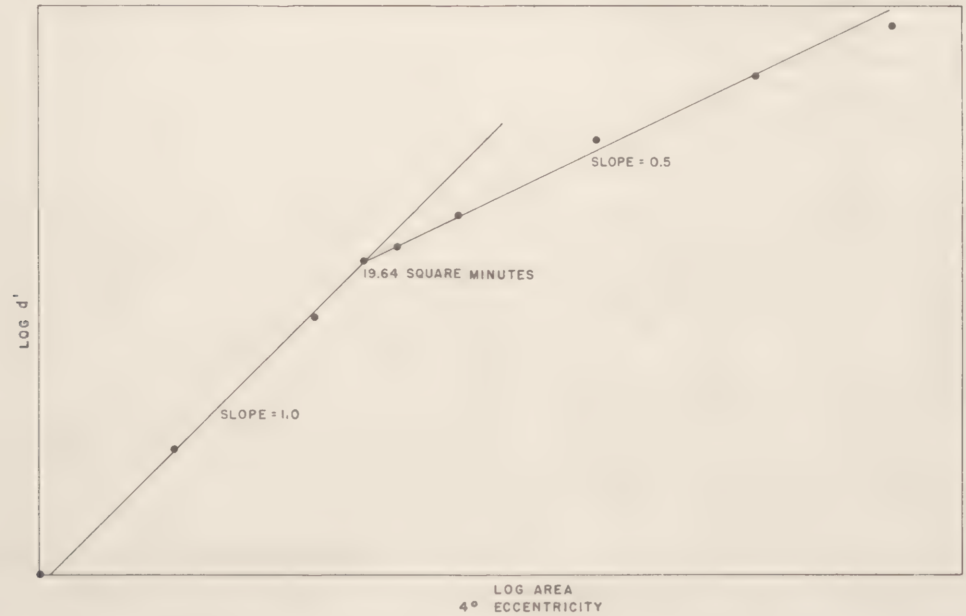


Figure 2

This procedure has been repeated for various positions in the visual field, and the minimum observable area along a single radial axis as a function of eccentricity from the center of the field is plotted in Figure 3.

It should be pointed out that this is not necessarily a different result for the same data previously shown in the literature. Graham, Brown, and Mote in their study of the area-intensity relation worked on the assumption that there is a constant neural effect at threshold. The validity of their experimental procedure and their analysis depends on this assumption. They analyzed their data in terms of the intensity necessary to lead to this constant effect for each area. This is the area-intensity relation they studied.

This study approaches the problem in a different way. Intensity is held constant, and detectability as a function of area is studied. Neither the experimental procedure nor the method of analysis depend for their validity on the threshold assumption. Experimentally, the forced-choice procedure is valid whether or not the threshold concept is valid. The analysis advanced here depends on the invalidity of the threshold concept, a position advanced and supported experimentally in a previous paper before this group.

Based on the above discussion it is now possible to show the effect of the ability to use precisely information about visual-field position for a signal of particular area, intensity, and duration on the ability to detect that signal, if the area of that signal is always smaller than the minimum observable area. d' varies inversely with the minimum observable area. Thus, if we take the data of Figure 3, and plot for each eccentricity the ratio of the minimum observable area for the center of the visual field to the minimum observable area for the degree of eccentricity, the result should be a sensitivity curve. Figure 4 shows this result. The solid dots are the calculated ratios. The crosses are the points obtained in a somewhat different manner. d''s for each eccentricity for a signal of constant intensity, size and duration were obtained experimentally. Then the ratio of d' for the eccentricity to the d' for eccentricity = 0 is the value represented by the cross. In general, this curve is slightly lower, perhaps resulting from a slightly lower average sensitivity of the receptors in the more peripheral regions under the conditions of light adaptation used; in the experiment the background illumination was approximately 10 foot-lamberts.

There is another explanation which could account for the discrepancy between the two sets of data. Each curve is based on a ratio, such that the value for eccentricity of 0 is present in each point on the curve.

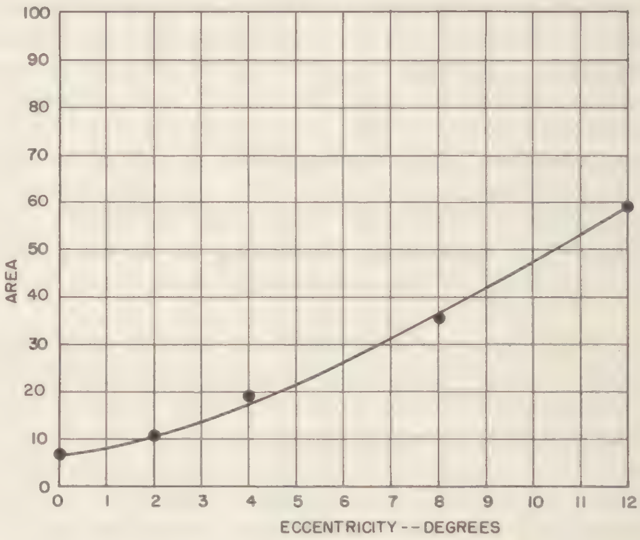


Figure 3. Minimum observable area.

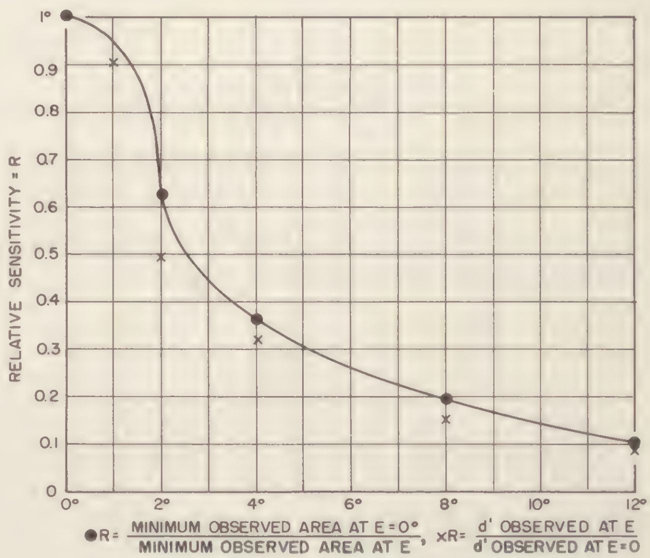


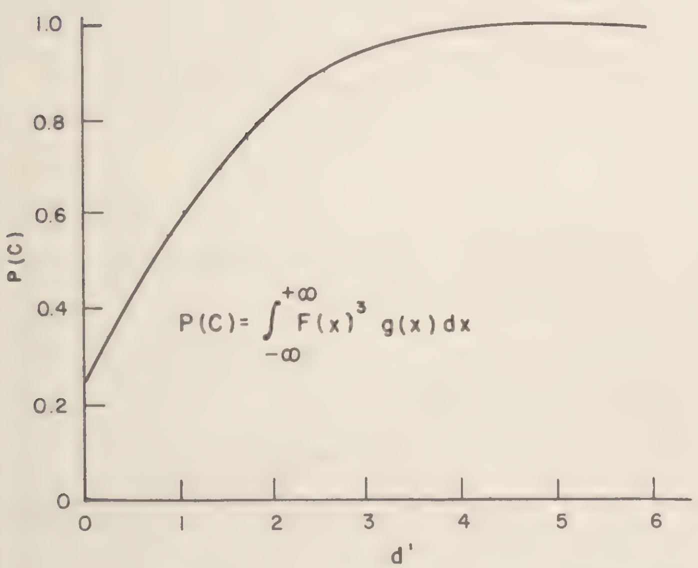
Figure 4

An error in the determination of this point for either curve would result in just such a constant error. The fact that the difference in three of the points is between .80 and .82 and the fourth .89 may suggest just such an error. The error is impossible to check as it depends both on experimental and mathematical procedures.

This discussion so far applies to the quantity of information involved in that knowledge that a signal, if it exists at all, exists in a particular portion of the visual field. The minimum observable area defines the preciseness of definition of location possible for any position of the visual field. This is a quantity necessary to the interpretation of data involving the removal of this information.

The experiments performed here are all of the null type. This is, each day's experiment has both the control data and the test data. The data permit comparison of detectability of signals is known to be at either of two locations. To describe the procedure, a single day's experiment will be considered. Throughout these experiments the background intensity was approximately 10 foot-lamberts, and the signal one minute in diameter. First, the signal is presented at a known location, 1° east of the fixation point and the detection probability is determined in a forced-choice experiment. Then the signal is presented at the known location 1° west of the fixation point and the detection probability determined. These are controls. Then the signal is presented randomly either 1° east or 1° west, and the detection probability again determined. It must be carefully noted that the observer is asked to give only information regarding existence of the signal, not its location. From the forced-choice theoretical curve (Figure 5) it is now possible to determine d' for the known and unknown location. The determination of d' is accomplished by treating the percentage correct for any signal intensity as an estimate of the probability correct shown on the ordinate. The value on the abscissa corresponding to this P(c) is the value of d'. For example, if an observer gives 40 correct answers in 50 trials for a given signal, then P(c) is said to equal .80. The value of d' corresponding to this is 1.8. This procedure was repeated for the following eccentricities along the horizontal axis.

Ratios of d' unknown to d' known are shown in Figure 6 for one observer for degrees of eccentricity along the horizontal axis of the visual field.



P(C) AS A FUNCTION OF d'
A THEORETICAL CURVE.

Figure 5. P(C) as a function of d' a theoretical curve.

Let us now return to the function showing sensitivity as related to eccentricity, and modifying each point on this curve by the ratio for the corresponding eccentricity from Figure 6. Figure 7 shows the result.

The results for this observer show the following:

(1) That the removal of knowledge has an increasing decremental effect when compared to the case of the knowledge present up to about 2.5° of eccentricity; then as we go beyond that point, the effect decreases.

(2) That if we consider only the case of unknown location, detection decreases with the distance between the signals up to 2.5° eccentricity, or 5° of separation, and then appears to have no further effect.

What kind of mechanism can lead to these results? First, let us hypothesize a mechanism which is essentially a narrow beam receiver.

This mechanism is central to the visual pathways, and at any instant in time can observe only a small part of the output of the visual pathways, representing only a small area centered around a particular location on the retina. The whole retina can be observed only if the center of observation can be shifted from point to point over the output of the pathways. If this is a scanning type mechanism, then it would take longer to move between two widely separated points than between two points close together. Such a mechanism can account for the data up to a separation of 5°. If only this type of mechanism exists, further separation should lead to further decrease in detectability, unless the observer can achieve this rate by sitting on one signal position and accepting a chance rate of detection when the signal happens to be at the other location. This latter behavior cannot account for the data because the d' ratio is too high.

However, suppose there is a second mechanism similar to a wide open receiver. The only function of such a receiver would be the detection of the existence of signals outside of the range of scan of the first mechanism. This is, of course, a mechanism of lower sensitivity because it must deal with noise over the whole retina, or a very large observation area. When the knowledge of the position involves a large observation area, and the two areas are sufficiently far apart so that they cannot both be observed during the existence of the signal, then it may be more intelligent to switch mechanisms, not using at all the information that the signal exists in one of two locations. Thus, for all positions farther than 5° apart, the same mechanism is used.

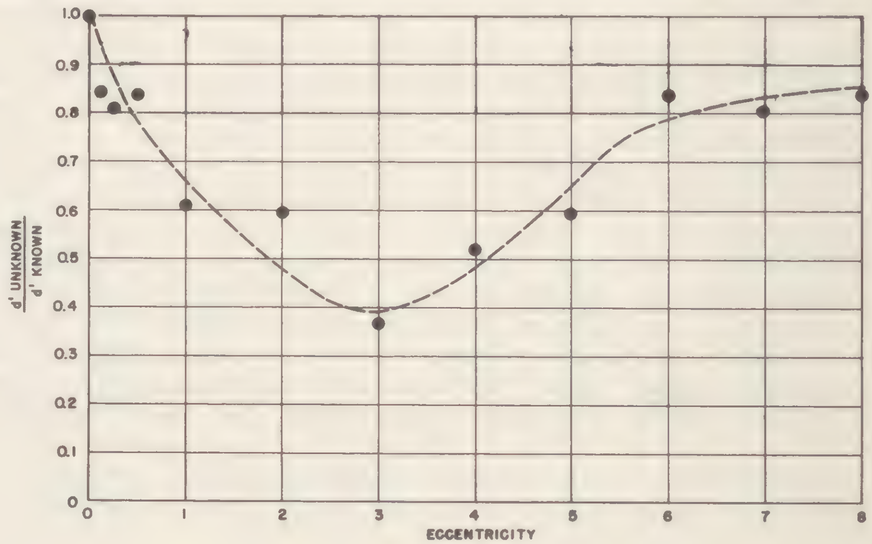


Figure 6

In order to describe more clearly the dual type mechanism suggested, a more simplified system is presented in Figure 8. This mechanism departs far from reality, showing single neurons from the receptor to the cortex and a more exact spatial mapping than probably exists, but it is far easier to talk about than a more realistic model. It must be remembered that it is a schematic diagram, rather than an exact histological representation.

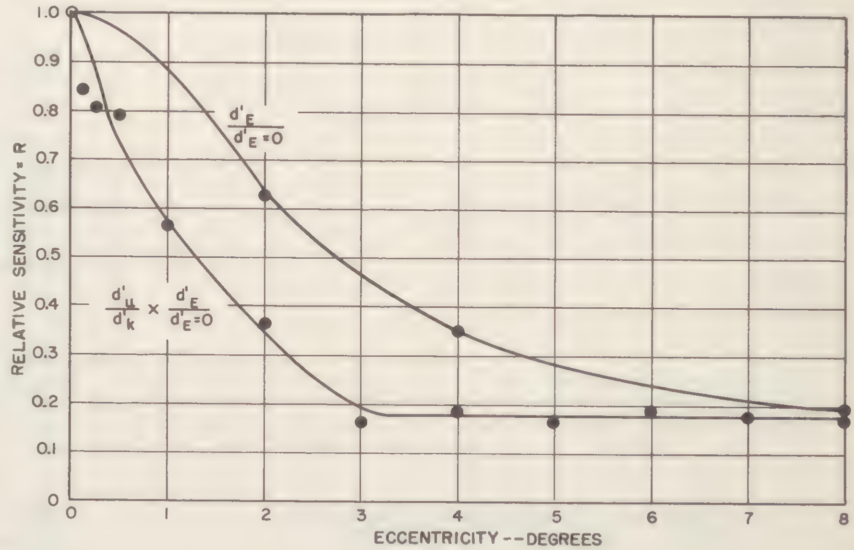


Figure 7

A, B, C, D, and E are locations in the visual field, with A the fixation point. Connections are shown as mapped on to the output of the visual pathway. The element marked "observer" can select that part of the output relevant to the knowledge of location of the signal. However, to shift from D to E it must pass through B, A, and C. To shift from B to C it needs to pass only through A.

According to the diagram, the minimum observable area is two receptors at the center of the field, and five receptors in the periphery. Knowledge that the signal will occur on any single receptor does not improve the observer's performance.

Now, let us assume that the observer knows the signal will occur either at A or B. It is possible to shift back and forth during the signal existence, reducing its effective intensity, but nevertheless introducing for consideration noise from only four receptors, as compared to the noise from all twelve receptors which enter the wide open mechanism to the right. Consequently, employment of the scanning mechanism should lead to better performance than would be achieved by employment of the wide open receiver.

On the other hand, compare the situation when the signal can be either at D or E. Here, in the known location there is noise from five receptors (the minimum observable area). In addition, in the unknown case, more information is lost in scanning because of the additional time spent in moving from D to E when compared to the case of moving from A to B. Even if it were possible to move instantaneously, the time would still have to be shared, and there is noise from ten receptors as compared to twelve in the wide open receiver. Thus, by drawing an extreme model, it has been possible to demonstrate a dual mechanism which can account for the data.

The dual-type mechanism has biological utility. The narrow beam receiver provides detailed information, and is the type of mechanism which would be used when attending an analytic-type task. The wide open mechanism serves as a detector of signals sufficiently strong to justify search at the expense of stopping concentration. In other words, it provides the possibility of detection without continuous search of the narrow beam receiver.

In interpreting this paper, a few words of caution are necessary. Only eccentricities of 8° or less have been considered. This means that only that part of the retina with an approximately uniform receptor makeup has been considered. When considering events further in the periphery the picture may be further complicated, particularly under conditions of dark adaptation. It can, nevertheless, be considered as a demonstration of a theory which accounts for the way in which knowledge of location of a signal is important in detection.

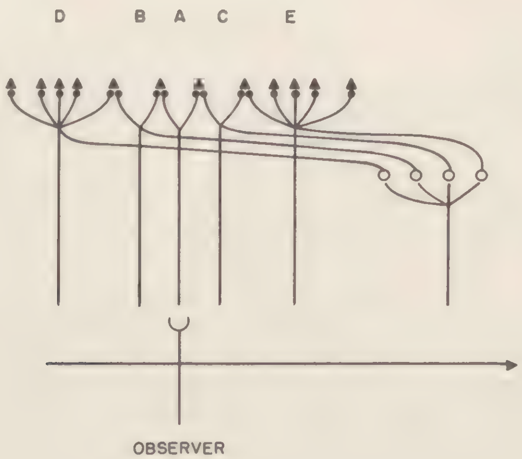


Figure 8

TWO EXPERIMENTS ON THE PRE-EXPOSURE TOLERANCE OF THE HUMAN FOVEA *

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Patricia I. McBride,
Joseph W. Wulfeck, and Leonard C. Mead

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Tufts College

Several studies have dealt with the relation between the course of foveal dark adaptation and the brightness and duration of the light to which the eye has previously been exposed.[1,3,5,6,7,8] The results have been generally consistent in indicating that the effect of increasing the brightness and/or duration of the pre-exposure light is to increase the initial threshold and to prolong the time required for the eye to reach a stable level of maximum sensitivity.

Since both brightness and duration of pre-exposure are varied, the question of whether or not their action is reciprocal is a relevant one. However, the nature of the effects of pre-exposure brightness and duration upon the course of subsequent dark adaptation is open to considerable controversy. Wald and Clark[9] found that when Brightness x Duration = C, rod dark adaptation takes place more slowly following pre-exposure to low brightness of long duration than it does following pre-exposure to high brightness of short duration. Data of Haig[4] however, indicate that duration and brightness of pre-exposure are reciprocal in their effects upon rod dark adaptation. Subsequent experimentation has not provided a resolution of the controversy.

To predict the relative effects of pre-exposure brightness and duration upon dark adaptation for the fovea is even more difficult than for the periphery, since less is known about the photochemistry of the cone system. The data of Mote and Riopelle[8] indicate a complex relation. They found that foveal dark adaptation curves were similar when the pre-exposure was to brightnesses and durations that gave the same B x D value, _if_ the highest brightnesses (11,300 and 5,650 mL) and longest durations (300 and 150 sec.) were involved. Similar dark adaptation curves were also produced by brightnesses and durations that gave the same B x D value if their lowest brightnesses (1,130 and 565 mL) and briefest durations (30 and 15 sec.) were involved. For none of their other pre-exposure combinations did constant products have similar effects, nor did the relation between the two variables appear to be a simple one. Other studies, e.g., those of Johannsen[6,7] show equally complex relations. To date most of such studies have been concerned primarily with relatively high values of brightness and duration, so that an investigation of the effects of these two pre-exposure variables in their lower ranges is invited. Such an investigation would be expecially interesting if the brightnesses were in that lower range at which small changes have a large effect upon visual acuity and related visual functions.

The range of pre-exposure brightnesses for the present experiment was chosen as a relatively unexplored one and as one through which visual acuity rises steeply. The specific brightnesses and durations were further selected so as to produce a number of different brightness x duration constants with some of the same constants produced by different B x D combinations.

* The experiments reported here constitute portions of a program of research which has been supported at the Institute for Applied Experimental Psychology, Tufts College, by the Human Factors Office, Rome Air Development Center, Griffis Air Force Base, Rome, N.Y., under U.S. Government Contract No. AF 30(602)-199.

The apparatus used was a modification of the Crozier-Holway discriminometer, built by the Scientific Specialties Corporation and modified in the Tufts laboratory. It consists of a triple optical system, each path independently controlled with respect to size, position, brightness, wavelength, and duration of exposure, and all producing images at the same plane in the visual field. The views afforded by each path can be simultaneously superimposed in the field or presented singly or in any combination.

In the present experiments a field approximately 27^{o} in diameter was seen in Maxwellian view. By means of appropriate shutters and filters it was possible to produce brightness changes in this field in the following sequence: (1) adapting level, (2) pre-determined brightness increment over adapting level, and (3) darkness. The duration of phases (1) and (2) could be controlled, and elapsed time during phase (3) could be accummulated. In the first of the two experiments to be reported here, phase (1) consisted of ten minutes of complete darkness; in the second experiment, phase (1) consisted of one of three brightness levels (namely, 0.10, 1.0, and 10. ft-L.) to which the eye was adapted for ten minutes. The pre-exposure period occurred in phase (2). In the first experiment, the pre-exposure phase consisted of 0.10, 1.0, 10., and 100 ft-L seen for 1, 10, and 100 seconds; during phase (3) the subsequent dark adaptation was traced by obtaining absolute brightness thresholds. In the second experiment, the pre-exposure phase consisted of the superposition of 1-, 2-, or 3-log brightness increments for these same durations on the three pre-adapted levels; again, the absolute brightness thresholds were taken during phase (3).

In each experiment, during adaptation (phase 1) and pre-exposure (phase 2) a cross-hair served as fixation point. The test patch used in phase (3) was a centrally located square, one degree on a side, which appeared for 0.033 seconds. In order to hold fixation while the absolute threshold for the test patch brightness was being determined, four orientation points formed a cross about the point at which fixation was desired; these points were blue (peak at 4100 A) and were approximately 20 seconds in diameter; the axes of this outlined cross subtended approximately 6^{o}.

The psychophysical procedure used was a modified Method of Limits which involved only ascending series; also, the first transitional judgment was accepted as the threshold in each series. Two trained observers served as subjects, using the preferred eye. Except during the earliest portions of each curve when haste was essential, test flashes were never presented oftener than once every three seconds in any one series. An effort was made to secure five threshold judgments within the first 100 seconds of foveal adaptation. Thresholds were taken until five consecutive ones were obtained which fell within the limits of 0.15 log units of brightness.

EXPERIMENT I

Monocular foveal dark adaptation after pre-exposure to various brightness-duration combinations on the dark-adapted fovea.

The results of this experiment are presented in Figure 1. The criteria which are customarily used to indicate the effects of pre-exposure conditions upon subsequent dark adaptation are three characteristics of the dark adaptation curve: (1) the initial point on the curve or the "instantaneous" threshold; (2) the shape of the curve; and (3) the time required for the curve to level off.

When the first criterion is applied to the results of the present experiment it was found that only three sets of pre-exposure conditions produce initial thresholds which appear appreciably higher than subsequent final levels of sensitivity for both observers: these are the thresholds following pre-exposure to 100. ft-L for 100 and for 10 seconds and to 10. ft-L for 100 seconds. One observer (PMcB) also showed an initial threshold higher than the final level after pre-exposure to 10. ft-L for 10 seconds. Although the variability apparent

in the data may obscure other differences, it would seem that only the most extreme brightness-duration combinations in the range explored here result in measurable decreases in sensitivity.

Applying the second criterion, visual inspection of the shapes of the curves in Figure 1 indicates that the curves for each observer following pre-exposure to 100. ft-L for 100 seconds are only slightly steeper than those following pre-exposures to 10. ft-L for 100 and to 100. ft-L for 10 seconds, which are remarkably similar to one another. The remainder of the curves, with the exception for PMcB, are thought to exhibit little more than variability about straight lines.

Application of the third criterion, the time required to regain maximum sensitivity, indicates considerable similarity among the curves which show any evidence of adaptation. In all four curves showing adaptation for either observer, complete recovery of sensitivity seems to have been achieved within 100 seconds in the dark.

The results do not demonstrate that either brightness or duration of pre-exposure has the greater effect upon foveal sensitivity. For example, the brightness difference between the initial and terminal thresholds expressed in absolute units for one observer (PMcB) is

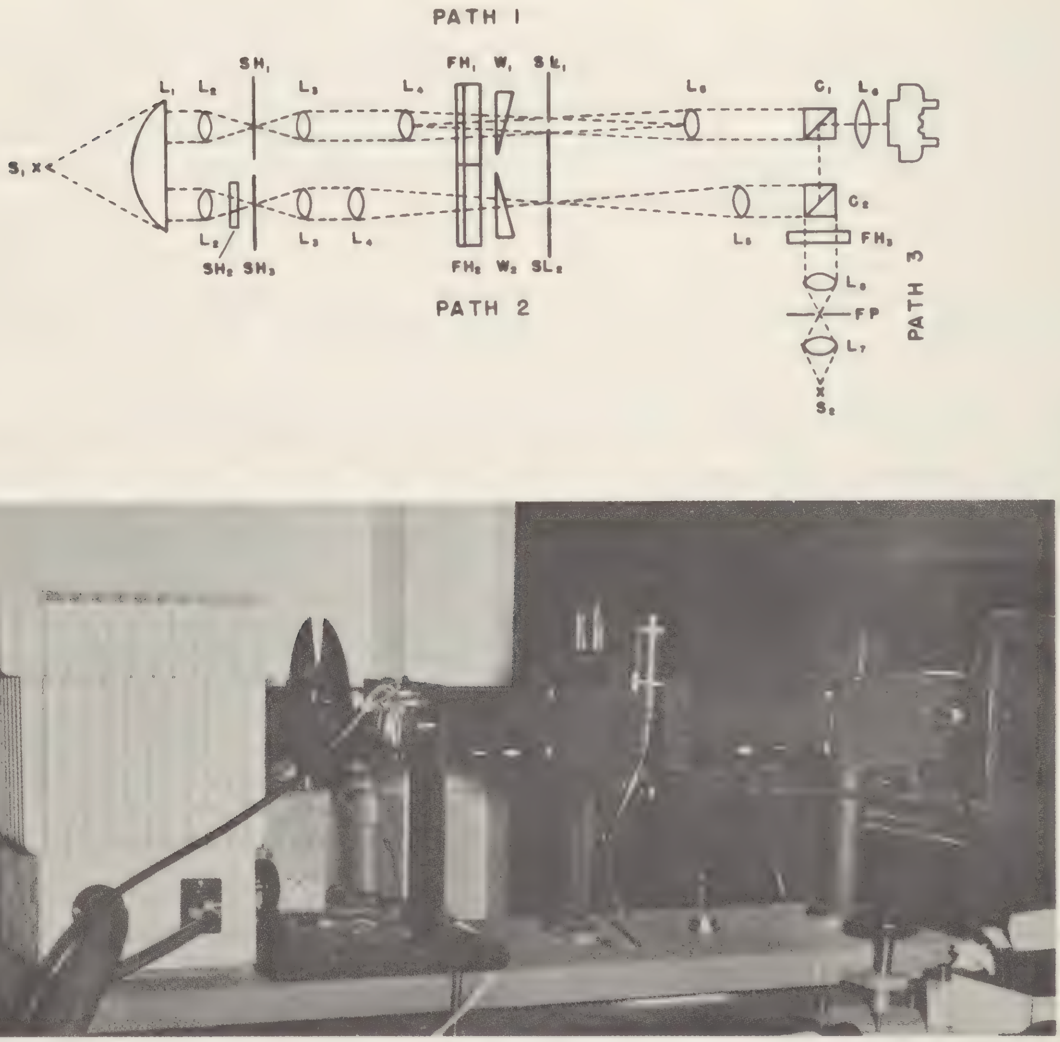

Figure 1

0.066 ft-L following pre-exposure to 100. ft-L for 10 seconds and 0.075 ft-L following pre-exposure to 10. ft-L for 100 seconds. For the other observer (JWW) these differences are 0.019 and 0.019 ft-L, respectively. Furthermore, it was pointed out above that the curves following pre-exposure to 100. ft-L for 10 seconds and to 10. ft-L for 100 seconds for each observer are more similar to each other than to any other curve obtained in the experiment. It is also apparent that in no case was dark adaptation measurable following pre-exposure to light equalling 100. ft-L-seconds or less. There seem to be no instances in which pre-exposure to a particular B x D product was followed by adaptation and different combinations of brightness and duration producing the same product were not followed by adaptation.

EXPERIMENT II

Monocular foveal dark adaptation after pre-exposure to various brightness-duration combinations on the fovea which has been light-adapted to differing levels.

In order to assess more clearly the effect of brightness-duration combinations on the fovea which has been adapted to different brightness levels, the foveal dark adaptation curves for each observer first were obtained after ten minutes adaptation to each of the three adaptation levels, but without the insertion of any pre-exposure stimulation between the light and dark adaptation. These results are shown in Figure 2.

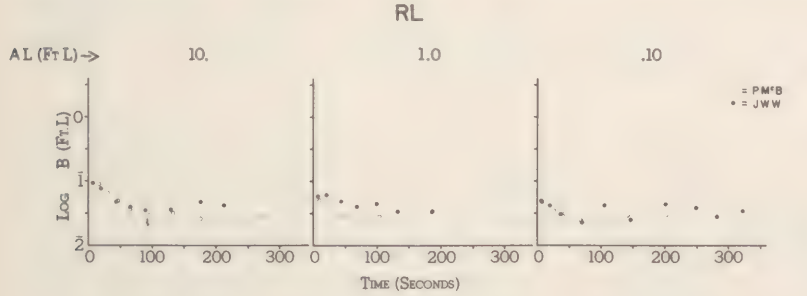

Figure 2

Inspection of Figure 2 shows that height of the initial point on the adaptation curves of each observer decreases as Adaptation Level decreases from 10. to 1.0 ft-L. As Adaptation Level decreases from 1.0 to 0.10 ft-L little, if any, lowering of the initial point occurs. A difference in the shapes of the curves can be observed between those obtained after 10. and 1.0 ft-L, but little, if any, difference is discernible between the curves obtained after 1.0 and 0.10 ft-L. Adaptation after 10. ft-L appears to be complete after approximately 100 seconds, whereas after 1.0 and 0.10 ft-L it appears to be complete before 75 seconds. It is clear that considerably more data are required to establish these relations firmly, especially since an inconsistency between these results and those of the first experiment is apparent. In the first experiment Brightness x Duration products of pre-exposure below 100 ft-L-seconds were not found to produce measurable adaptation. In the present experiment, an Adaptation Level of 0.10 ft-L for 10 minutes yields a product of only 60 ft-L-seconds and yet some adaptation appears to have resulted. This effect, if real, suggests that at low brightnesses, duration and brightness do not remain reciprocal and that duration becomes the more effective in determining the subsequent adaptation.

The data just presented may be used as a base-line to assess the effects of the pre-exposure brightnesses and durations already described. Results are shown in Figure 3. Consideration of Figure 3 shows that, in terms of any of the usual criteria, there are some combinations of pre-exposure that even when superimposed upon an Adaptation Level other than darkness fail to produce measurable changes in the subsequent dark adaptation process. With an Adaptation Level of 1.0 ft-L and pre-exposure of 10. ft-L for 1 second, the presence of dark adaptation is equivocal, as it is in the case of Adaptation Level 0.10 with pre-exposure of 1.0 ft-L for 100 seconds. No measurable adaptation appears to be present after Adaptation Level of 0.10 ft-L with pre-exposure of 1.0 ft-L for 10 and 1 seconds and after Adaptation Level of 0.10 with pre-exposure of 100. ft-L for 1 second.

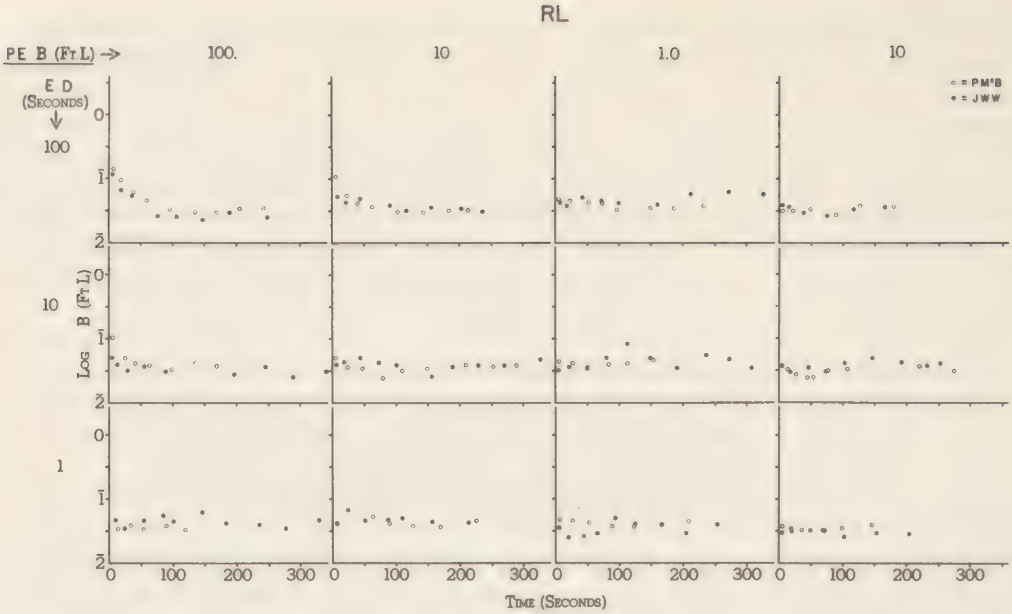

Figure 3

However, it must again be emphasized that the first point of any curve was never obtained with 4 seconds (7 on the average) after the cessation of pre-exposure, so that these results must be carefully qualified in terms of the apparatus and procedures used.

Other relations among the results are complex, although some appear to be quite systematic. Applying any of the usual criteria it seems that for any combination of Adaptation Level and pre-exposure brightness, decreasing pre-exposure duration tends to be accompanied by decreasing adaptation. Likewise, for any Adaptation Level and pre-exposure duration, decreasing pre-exposure brightness appears to be accompanied by decreasing adaptation. In several instances, a particular combination of pre-exposure brightness and duration tends to be accompanied by less adaptation as the Adaptation Level upon which it is superimposed is decreased.

The data in Figure 3 (in which various pre-exposures were inserted between light and dark adaptation) are compared in Figure 4 with the data of Figure 2 (in which there were no pre-exposures between light and dark adaptation). The closed circles in Figure 4 are the data for both observers after adaptation to each of the three adapting levels but without any pre-exposures; the combined data are repeated three times after an adaptation level of 10 ft-L, six times after an adaptation level of 1.0 ft-L, and nine times after an adaptation level of .10 ft-L. The open circles of Figure 4 are the data which appeared in Figure 3 for the same two observers. In Figure 4, therefore, the differences, if any, between the open and closed circles should be attributable to the various pre-exposure combinations.

From visual inspection of these data it would appear that differences occur only following those brightness x duration products which equal 10,000 foot-lambert-seconds. For all three light adaptation levels it seems to require a pre-exposure brightness of 100 ft-L and a pre-exposure duration of 100 seconds before the subsequent dark adaptation curve differs from that obtained when the pre-exposure was omitted. Brightness x duration products less than 10,000 foot-lambert-seconds do not seem to produce curves which are clearly or consistenty different from the non-pre-exposure conditions. The open-circle curve which differs most markedly from the closed-circle data is that obtained following the lowest adaptation level (.10 ft-L) with a pre-exposure of 100 ft-L and a duration of 100 seconds; on the other hand, this particular dark adaptation curve does not differ markedly from the ones obtained at the other two higher adaptation levels following the same pre-exposures. Thus, no particular case can be made for a progressive effect of previous light adaptation levels.

Summarizing these two experiments, we may say that the fovea has been shown to maintain its sensitivity to a remarkable degree even when pre-exposed to moderate brightness levels of 1-100 seconds duration. In the first study the dark-adapted fovea showed no clear-cut loss of sensitivity when the brightness x duration product was less than 100 foot-lambert-seconds; even when adaptation did occur, recovery of sensitivity was achieved within 100 seconds. The second study showed that when similar pre-exposures were applied to the light-adapted retina, no foveal sensitivity loss appeared for stimulation less than 10,000 foot-lambert-seconds. It is not possible from the studies to decide whether there is full reciprocity between brightness and duration. The extension of these observations into the peripheral retina is obviously desirable. Even the present results, however, have important applications for the environmental controls which are applied to human observers whose foveal adaptation may be interrupted by light flashes for brief periods of time.

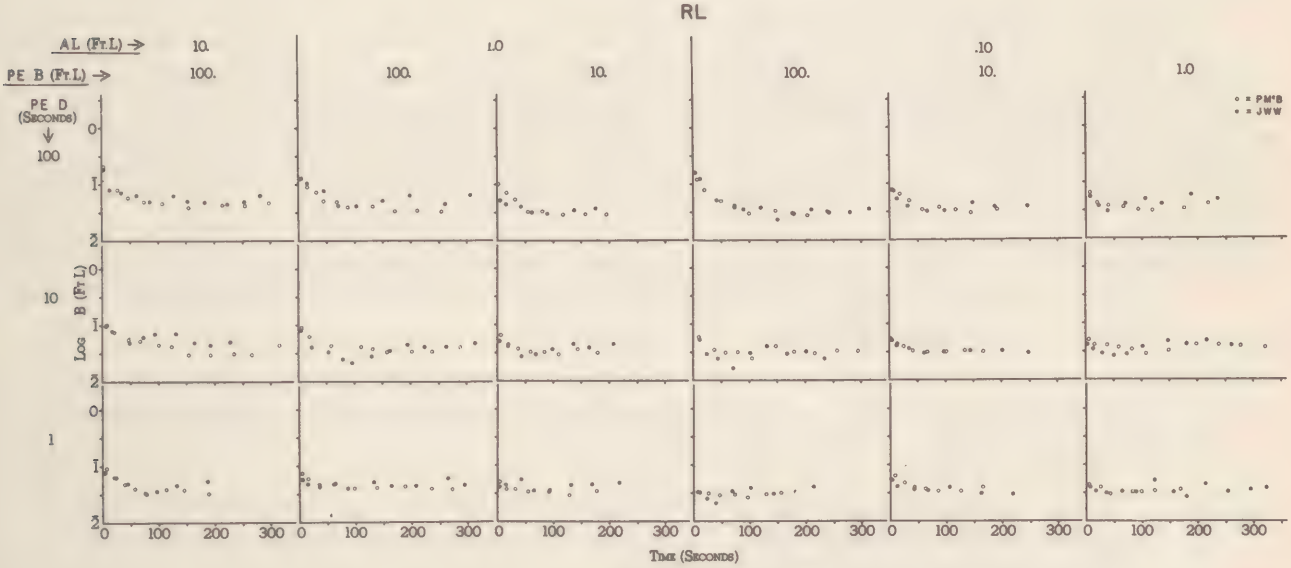

Figure 4

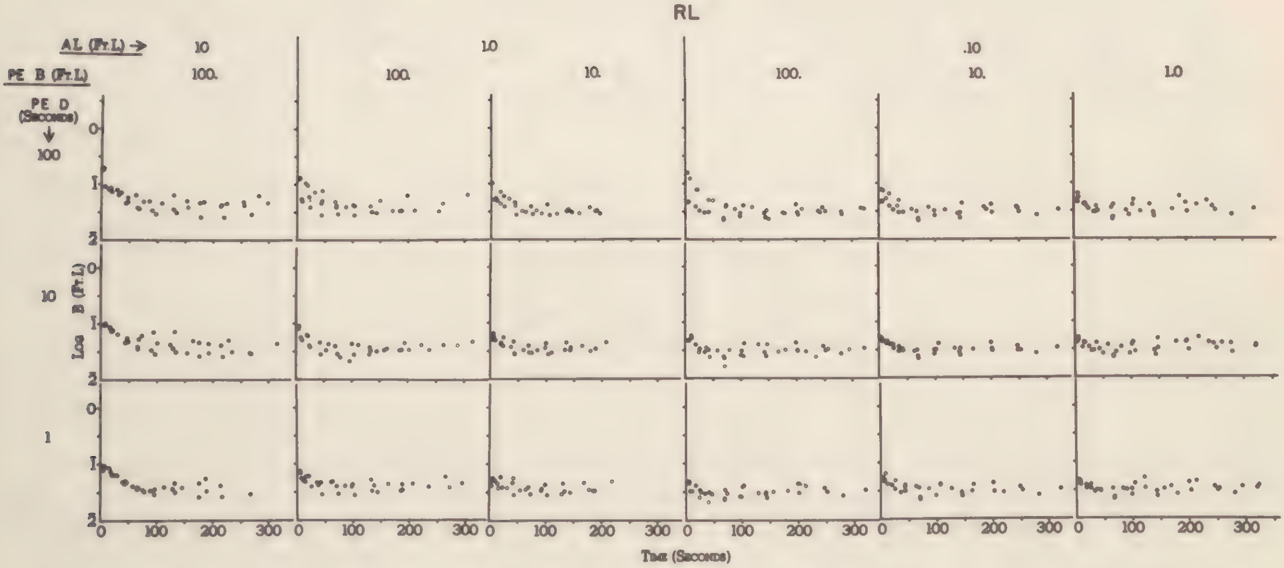

Figure 5

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REPORT ON COMPLETION OF A SECTION OF THE JOINT SERVICES HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN - VISUAL PRESENTATION OF INFORMATION

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I would like to present a brief report on the completion by the Aero Medical Laboratory of one section of the Joint Services Human Engineering Guide to Equipment Design, dealing with the design of displays for visual presentation of information. This section has been published as Wright Air Development Center Technical Report No. 54-160, titled, "Visual Presentation of Information", by Charles A. Baker and Walter F. Grether, August 1954. This Technical Report has been issued as a preliminary draft of a part of the Human Engineering Guide being prepared under the direction of the Joint Services Steering Committee for the Guide. After further review and revision it is planned that this material will become that part of the Guide which deals with the visual presentation of information. The purpose of the Human Engineering Guide to Equipment Design is to provide designers of military equipment with human engineering data and general design recommendations for maximizing efficiency of human operation and use.

This Technical Report provides a compilation of general human engineering recommendations and presents some of the supporting data which should aid the engineer in providing the most satisfactory visual presentations of information. The Report is divided into seven major chapter headings, covering Mechanical Indicators, Warning Devices, Cathode Ray Tubes and Signal Coding, Printed Materials, Instrument Panel Layout, Lighting, and Visual Detection and Identification. In the chapter on Mechanical Indicators are discussed factors important in the selection of symbolic and pictorial displays for different uses, scale design and pointer design for quantitative and qualitative reading, instrument identification labeling, and design of numerals and letters for maximum legibility. Under the heading of Warning Devices are discussed factors affecting the design of Warning Lights, caution indicators, binary indicators such as on-off signal devices for functional indicators.

In the chapter on Cathode Ray Tubes and Signal Coding, recommendations are made concerning methods for indicating range and bearing on search-type radar displays, coordinate information display methods, and the display of coded target information, as well as a general discussion of factors important in visibility and resolution of targets on Cathode Ray Tube displays.

The chapter on Printed Materials contains discussion and recommendations for legibility of printed matter, including books, pamphlets, decals, check-lists and labels, and for design of graphs, tables, and scales for presenting numerical data.

There is a chapter on instrument panel layout, in which are discussed factors affecting instrument priority, position, viewing angle and distance, and instrument arrangements and pointer alignment, as well as a check-list for good panel layout and representation of space-position information.

A chapter on lighting is included, presenting a general discussion of terms used in illumination and visual research and practice, discussion of general workplace lighting, and a discussion and recommendations for instrument and control console lighting.

In the chapter on Visual Detection and Identification, a discussion is presented of factors which affect visual acuity, detection and recognition of colored targets, pattern recognition

and indentification, magnification aids to vision, and the visual presentation of size, range, velocity, and acceleration information.

A detailed subject index and a selected bibliography, as well as a Table of Contents, are provided as aids in finding appropriate recommendations on problems which confront the engineer engaged in equipment design.

The Technical Report is available to all Government Service Organizations and contractors through the Armed Services Technical Information Agency, Knott Bldg., Dayton, Ohio. It has also been released for sale to the general public through the Office of Technical Services, Department of Commerce, Washington 25, D.C. Members of the Vision Committee are invited to obtain copies of the report for their use and also for review and comment. The Aero Medical Laboratory will appreciate any comments which will be useful in revising or adding to the material prior to its publication in the Joint Services Human Engineering Guide to Equipment Design.

DESIGN CRITERIA FOR GRAPHIC AIDS*

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INTRODUCTION

The present report is intended to communicate a brief review of the conduct and findings of a project on the development of design criteria for graphic aids. As used in this report graphic aids refers to two-dimensional, static (non-motion picture) visual displays, such as wall charts or projected slides or transparencies, which are used for teaching or other educational functions. It is also assumed that such graphic aids are normally viewed under typical classroom situations of group viewing, far distance vision, and illumination levels of some 25-50 ft. C. on wall charts and some 5-12 ft. C. of reflected light from projected materials.

The circumstances leading to the instigation of the project arose from the recognition that although graphic aids are extensively used in various military situations, there existed few, if any, objective criteria by which such aids might be evaluated as to their adequacy by their designers and users.

PROCEDURE

Though originally planned as a combined bibliographic and experimental approach, circumstances restricted the utilized procedures to a search of the literature and the rational extrapolation and generalization of design criteria.

Considerations of historical and substantive nature indicated that the literature search be extensive in regard to various areas, specialties, or disciplines related to visual communication. As such the literature search screened some 1200 to 1300 references from the areas of audio-visual education, vision, perception, learning, communication, visual art, visual advertising, engineering drawing, statistical graphics, etc.

From these screened references, some 400 of the most relevant were annotated and included in a Special Devices Center Technical Report. The intent of that report was two-fold. First, the report was to serve as a fund of information from which preliminary formulations of design criteria might be made. Secondly, the report was to serve the function of informing researchers and practitioners in the design of graphic aids with a somewhat comprehensive review of the types and quality of information relevent to their problem.

The final phase of the project was characterized by the systematic review of the information obtained in the literature search and the induction and formulation of principles and criteria pertaining to the design and utilization of graphic training aids.

DESIGNATION OF THE GENERAL CRITERIA

The most general of the derived design criteria for graphic training aids were those of Relevancy, Legibility, Comprehensibility, and Attention-Value. Criteria with such labels

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* This project was carried out at the Institute for Applied Experimental Psychology, Tufts College, under contract with the Special Devices Center, Office of Naval Research.

and operational definitions of varying degree of similarity were found in a large number of the indicated references. Though not completely independent and mutually exclusive, they are valuable in thinking and working with the problem at hand. As used in the present paper these criteria are defined as follow:

1. A graphic aid is said to have met the criterion of Relevancy when its content contains that which the instructor or communicator wishes to communicate to the viewer. Relevancy of graphic aid content may be determined by degree of interdependence of aid content with instructor's commentary, relatedness of pictorial aid content to verbal content of the aid, and relatedness of aid content to the goal or objectives of the communication.

2. A graphic aid is said to have met the criterion of Legibility when every indicated element of the aid can be seen or detected. This criterion refers to the adequacy of the aid and its content as a psychophysical stimulus. The legibility of graphic aid content is determined by a whole host of variables such as size of detail, spacing of elements, brightness contrast, etc.

3. A graphic aid is said to have met the criterion of Comprehensibility when the content of the aid is understandable and meaningful to the viewer. This criterion refers to the adequacy of the aid and its content as a recognizable depiction to the viewer, of the object, process, concept or other referent intended by the designer. The comprehensibility of an aid is, in part, measured by the degree of bewilderment, confusion, or error manifested by the viewer in his interpretation or attempted understanding of the aid.

4. A graphic aid is said to have met the criterion of Attention-value when it competes successfully with other stimuli for the visual fixation and intellectual preoccupation of the viewer. The attention-value of an aid is manifested by frequency and duration of visual fixation, viewer's preferences for the aid's characteristics, and viewer's verbal estimates of the aid's "vividness" or "demand" value.

SPECIFIC DESIGN PRINCIPLES RELEVANT TO THE GENERAL CRITERIA OF GRAPHIC AID DESIGN

It is the intent of this portion of the paper to specify in precise and concrete form a number of design principles and rules which are, in one way or another related to the more general criteria just discussed and which are illustrative of many others derived during the project.

In regard to the general consideration of relevancy of aid content to the objectives of the instruction or communication, the following specific rules are applicable to the aid's design:

1. Content, both pictorial and verbal, which does not contribute directly both to the general teaching aims of the program and to the purpose of the single lesson, should not be included in the aid. The application of this criterion is primarily dependent on the judgment of the curriculum expert or instructor.

2. When the objective of the communication is to teach recognition of a real object, a photograph or a faithfully correct drawing should be used. This criterion would imply fidelity of depiction including that of color.

3. When the objective of the communication is to teach skills of operation, use pictorial content which shows how the task is performed and how the manipulated equipment appears to the operator during the manipulation. This criterion implies the use of "bird's-eye" views and overprinting of directional hand movements.

In regard to the general design criteria of legibility of aid content, the following specific rules are applicable to the preparation of the aid:

1. Under most normal circumstances, maximal contrast and hence maximal legibility is obtained when aid content is depicted in black on a white background. In order of decreasing contrast and less than black on white, are black on yellow, black on yellow-green, black on orange, black on green, black on red, black on blue-green, and black on blue.

2. Under normal circumstances, capital letter or pictorial detail height and line width for various viewing distances should be in keeping with those specified in Table I.

Table I

DESIGN CRITERIA FOR GRAPHIC AIDS
Recommended Capital Letter of Detail Height and Stroke
or Line Width (inches) for Legibility at Various Viewing Distances

Distances from rear of Audience to Graphic (feet)	20/40 Vision Recommended		20/20 Vision Minimum	
	Letter Height *	Stroke Width	Letter Height	Stroke Width
10	3/8	1/16	3/16	1/32
15	1/2	3/32	1/4	3/64
20	11/16	5/32	11/32	5/64
30	1	7/32	1/2	7/64
40	1-3/8	5/16	11/16	5/32
50	1-11/16	3/8	27/32	3/16
70	2-3/8	1/2	1-3/16	1/4
100	3-3/38	3/4	1-11/16	3/8
200	7	1-1/2	3-1/2	3/4

* Type point size equivalents for the indicated letter heights may be computed by dividing the Table value by 1/72 or 0.01384 of an inch. Approximate equivalents to some of the Table values are available in Leroy Lettering Templates and pens.

3. Inter-letter spacing of capital letters forming a word should be approximately 50% of the capital letter "U", whereas interword spacing of words composed of capital letters should be 1.5 to 2 times the width of the capital letter "U" in the size and style of letter being used.

4. When designing graphics to be used under colored illumination, use white backgrounds to minimize the display's color changes which might result from the lighting.

5. All labels should be horizontal, never vertical.

6. Letter styles should not contain serifs, hair lines or very small gaps or open loops.

7. All graphics should contain information on limiting circumstances for effective viewing to aid in preventing inappropriate utilization of the aid.

In regard to the general design criterion of comprehensibility, the following specific rules are applicable to the aid's design:

1. When the intended audience is of low mental ability or poor previous schooling, use concrete and exact pictorial content, whereas when the intended audience is advanced in intelligence or training use abstract or symbolic pictorial content.

2. Pictographic symbols, which are used in quantitative or statistical graphics, should be highly simplified, easily recognized, and familiar silhouettes of the object.

3. Indicate the true size of a depicted object by presenting a second but familiar object drawn to the same scale as the original object, presenting a linear scale beside the pictured object, presenting a numerical value of the object's true size, or presenting a caption indicating the fractional equivalence of the picture size to normal size.

4. When designing flow charts, be sure to have well marked Start and End points and legible arrows to show the direction of flow.

5. When comparing quantities by means of pictorial graphs, vary the number of symbols rather than the size of symbols.

6. The depiction of a hierarchy by a circular arrangement is not recommended.

In regard to the general design criterion of attention-value, the following are illustrative of the design principles which are applicable in the preparation of the aids:

1. When possible, aids should be designed in keeping with the following order of preferences for various types of pictorial material:

(a) colored pictures and illustration, first; black and white pictures and illustrations, second; line drawings, third; and silhouettes, last.

(b) pictures with people, first; pictures without people, last.

(c) realistic pictures, first; stylized or abstract pictures, last.

2. Increased attention value may occur with unfamiliar colorings of familiar objects or unconventional color-reversals.

3. When color has been found to facilitate retention of aid content by increasing attention-value, the following colors have shown decreasing mnemonic effectiveness: red, green, yellow and blue.

4. All application of attention-gaining devices such as reduced contrast, unique color, cross-hatching, unique symbology, etc., should <u>not</u> be used if legibility or comprehensibility are thereby limited.

In addition to the illustrative rules and principles of graphic aid design presented here, a number of others have been formulated in regard to other features of graphic aids such as styles of lettering, types and characteristics of layouts, captioning and labeling, and aesthetic and emotion-provoking implications of graphic aid design. Such information as has been derived should be appearing in a Special Devices Center Report sometime in the near future.

EVALUATION AND SUMMARY

Having indicated the sources, procedures, and results of the present attempt at the development of design criteria for graphic aids, there remains the task of reporting the project staff's evaluation of its efforts and products.

In regard to the notions, principles, and criteria derived on the project, it is recognized that they require cross-validation. Though their basis rest in experimental fact; they have not, for the most part, been systematically evaluated under such conditions as are usually encountered in the classroom situation. Such cross-validation studies would be most appropriate within the problem areas of:

1. Legibility requirements for verbal and pictorial detail.

2. Comprehensibility characteristics of various pictorial forms and layout variations.

3. Variations of attention-getting devices and their effects on learning and retention, etc.

Secondly, it was the opinion of the project staff that certain problems could not be answered on the basis of presently available knowledge. Typical of these problems are the following:

What is the optimal amount of information to be contained in a graphic aid? This question presupposes the availability of measures of both pictorial and verbal information which are applicable to the content of visual aids. Within the knowledge and experience of the project staff, no such measures exist. Until such measures are developed and exploited the determination of such design criteria remains either an art or a highly time-consuming empirical evaluation of individual aids in individual situations.

Thirdly, it was the firm opinion of the project staff that the problem of making graphic aids more effective was a special case of the more general problem of effective visual perception, communication, and learning. As such, it seems essential that progress on such problems will necessarily involve both an historical and interdisciplinary approach which encompasses such specialities as art, visual advertising, education, and the psychology of vision, learning and communication.

In summation, a report has been made on a project oriented toward the formulation of design criteria for graphic training aids as used in the military training situation. After a specification of bibliographic procedures used in the effort, a number of illustrative rules and principles have been presented and related to four general design criteria of graphic aids, i.e., Relevancy, Legibility, Comprehensibility, and Attention-value. Finally, an evaluation by the project staff has been stated pertaining to the limitations of the derived criteria and as to the types of research needed to extend the products and findings obtained under the present project.

STIMULUS CHARACTERISTICS DETERMINING SPEED OF CLASSIFYING VISUAL PATTERNS

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The present paper reports some of the results from a program of research which has been supported for the past three years by the Office of Naval Research. The research was undertaken as the outgrowth of discussion with Dr. Henry Imus, and with Dr. Arnold Small and members of the staff of the U.S. Naval Electronics Laboratory. It was agreed that the program would deal with variables relevant to the design of visual displays for sonar and radar type information. We had in mind particularly the visual display of an amplitude-modulated signal of the kind employed in active sonar ranging. An illustration of such an amplitude modulated signal is shown in Figure 1. It was agreed that the program would emphasize problems of speed of recognition, classification, and positive identification, rather than problems associated with target detection. The concepts and techniques of information theory were to be employed where they were applicable.

Figure 1. A typical amplitude-modulated signal, as it would appear on a cathode ray tube display.

The first year and a half of research were devoted to exploratory studies and to a comprehensive methodology study, which was reported to the Vision Committee at the San Diego meeting and has since been published elsewhere.[1]

The topic that has been of major interest to our group for the past year and a half is the investigation of a series of statistically-defined variables affecting the speed of visual pattern identification. During this time my associates have included Dr. Oscar S. Adams (now at Emory University), Dr. Maurice Rappaport (now at the Applied Psychology Unit, Cambridge University, England), Meyer Weinstein, and Nancy Anderson. Dr. Alfred Leonard of the Applied Psychology Unit has recently joined the staff for a period of one year.

In studies of visual discrimination it is customary to specify the stimulus in terms of the characteristics of a particular figure, either by reference to qualitative aspects such as simplicity, regularity, symmetry, or texture [6,7,11] or else by reference to quantitative properties such as area, contrast ratio, perimeter, and maximum dimensions,[4] number of elements,[5] number of similar angles,[5] or number of indefinitely extended straight lines.[2] It is also possible, however, to define certain statistical properties of figures, properties that arise from membership in some larger class or population of figures. The latter approach is suggested primarily by considerations of information theory, although it is clearly

related to the approach used by investigators who have studied the effect of context and verbal instructions and the effect of language habits on the perception of printed or spoken English and the perception of drawings.[3,8]

The visual forms employed in the present studies are generated by sampling, in accordance with specified rules, from a finite and precisely specified population of figures, and the variables studied pertain to the population and the method of sampling. Figures are low on a scale of meaningfulness. They are a uniform, non-textured black on a white ground, the distinctive characteristics of each figure being its contour.

The discrimination task is one in which S is required to locate a designated suprathreshold figure when it is presented as one of a subset of figures selected by similar sampling procedures. This is the type of recognition task that confronts an individual who is asked to identify a suspect in a police lineup, to classify a sonar return, or to recognize his car in a parking lot.

The principal variables studied to date include: (a) complexity, (b) redundancy, (c) homogeneity, (d) orientation, and (e) noise. Complexity is perhaps the key concept in the present formulation. The degree of complexity of the contour of an experimental visual pattern is here defined, not by any measurable aspect of a particular figure, but in terms of the size of the hypothetical population of figures that can be constructed by operations similar to the ones that produced the experimental figure. It is never possible to determine exactly what constitutes an hypothetical population from the viewpoint of the S in an experiment; it is possible, however, to establish rules for the construction of figures and to specify precisely the number of different figures that can be generated by use of these rules. We have done this in the manner illustrated in Figure 2.

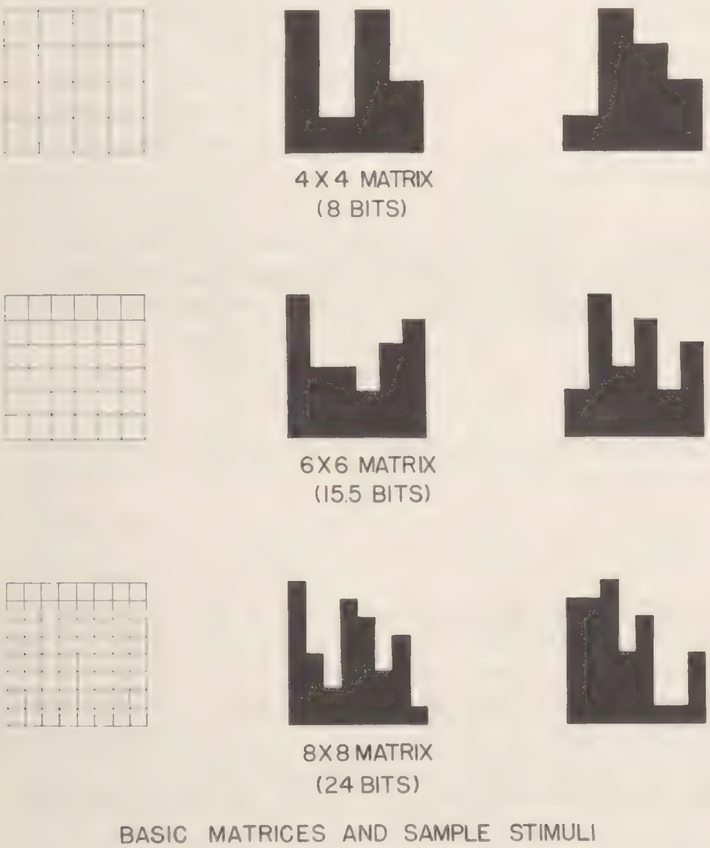

Figure 2. Three of the matrices used in generating stimulus figures, and examples of figures generated within each matrix. The lower left-hand figure was constructed by random sampling of column heights without replacement; the lower right hand figure was constructed by random sampling with replacement.

The area in which the figure is to be constructed is divided into some number of rows and columns. The resulting cells determine the units of area from which the figure is constructed. Adapting the idea of an amplitude-modulated signal, we start at the bottom of the first column and select some number of units of area greater than zero. A bar of that amplitude is constructed in the first column. The amplitude of the bar in the second column is determined in a similar manner and the process is continued until a complete figure is generated. The rules for the generation of figures are treated as an experimental variable. One possible rule is that the height of each bar be determined by a random process, and independently of every other bar. Maximum complexity is defined as the $\log_2$ of the number of different figures that can be constructed in this manner. By placing various

constraints on the sampling process, figures of a statistically specified degree of redundancy can be produced. One type of redundancy, for example, results from sampling without replacement, i.e., by using each amplitude only once. This particular sampling rule insures that all figures will have the same area and the same number of corners or discontinuities.

Redundancy is defined as one minus the ratio of actual to potential complexity. Thus, if r is the number of categories of column height, then sampling without replacement from the symmetrical matrix shown in Figure 2 permits the generation of r! figures, as compared with the r^r figures possible with random sampling, and thus provides figures whose relative redundancy is

$$1 - \frac{\log r!}{\log r^r}$$

or about 43%. As another example, a bilaterally symmetrical object, such as an ink bottle, is completely specified (if one knows that it is symmetrical) by one-half of its contour and can thus be said to be at least 50% redundant. It should be emphasized that redundancy can be introduced in many different ways and that the method of introducing redundancy may be as important, or even more important, than the actual amount of redundancy.

THE RECOGNITION TASK

The figure recognition task was selected on the basis of the data obtained in the earlier methodology study.[1] In this study it was found that measures of sorting or recognition time are correlated with learning trials and error, as well as with the time required to recognize and name a figure. All of these measures appear to be valid indices of the type of performance that we want to maximize through optimal display design. The recognition task has a decided advantage over the other tasks in that no extensive training is required and a great deal of data can be collected in a relatively short time.

A view of the sorting board used to provide the recognition task is shown in Figure 3. The figure to be identified on a given trial is placed at the top of the board and remains in view throughout the trial. The task is to examine the figures in each row of the sorting board and to identify the test figure, which appears once in each row. The order of the figures in each row is determined at random with the single restriction that the test figure not appear directly below itself in adjacent rows. As soon as S locates the test figure, he turns it over. The incidence of errors in this task is very low. However, errors are readily apparent from an easily-read color code which appears on the back of each figure. The time to complete each row and the time to complete all rows is recorded to the nearest 0.1 sec.

Each figure in the subset constituting the sample serves once as the test figure during each trial.

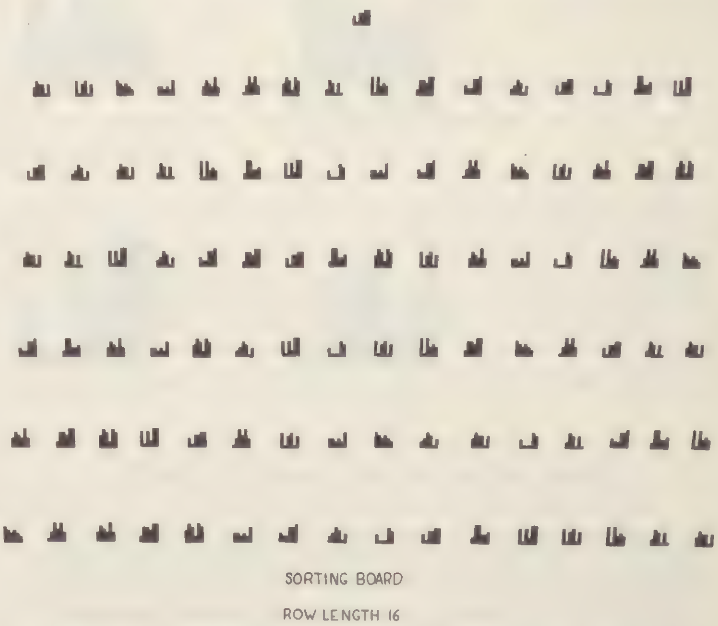

Figure 3. View of the sorting board, sixteen figures per row.

The order in which different figures are sorted is determined by

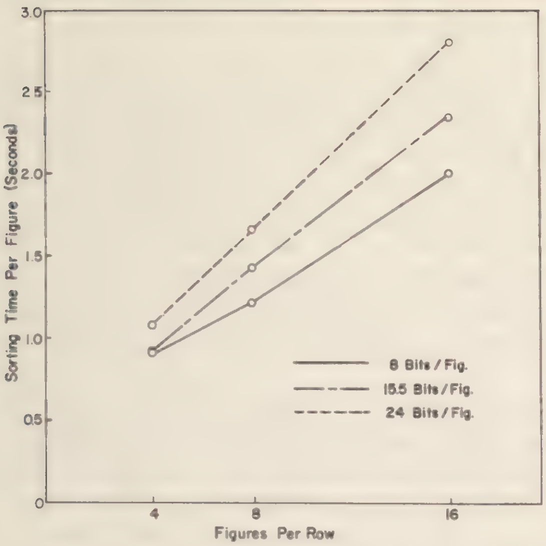

Figure 4. Sorting time per figure as a function of the number of confusion figures and figure complexity.

a random process and the sequence is different for each S. The Ss in all experiments were highly practiced and were paid for their services.

RESULTS

Complexity, random figures. — Figures of three levels of complexity were constructed by use of a 4x4 or 16-cell matrix, a 6x6 or 36-cell matrix, and an 8x8 or 64-cell matrix. The particular samples of figures used in the study were selected by random sampling without restraint from the total of 4^4 or 256, 6^6 or 46,656, and 8^8 or 16,777,216 figures, respectively, that can be constructed in these three matrices. The index of complexity of these figures, $\log_2$ of the population in each case, is 8, 15.5, and 24 bits, respectively, All the matrices were of equal over-all area (1.4 x 1.4 in.).

The number of figures in each row of the sorting board was also varied in three categories, 4, 8, and 16. When the number of figures in the subset was small, figures were spaced farther apart on the sorting board. The decision to hold row length constant was an arbitrary one.

The results of this experiment, expressed as the average time required to locate a figure of any given level of complexity from among a given number of confusion figures is shown in Figure 4. The data are based on three replications of the experiment using different samples of figures. Recognition time was found to increase as the number of alternative figures increased and also as complexity increased, except that there appeared to be no difference between the two lowest levels of complexity for the smallest number of confusion figures per row. Both effects were significant at the .01 level of confidence. There was no significant differences among the data for the three replications.

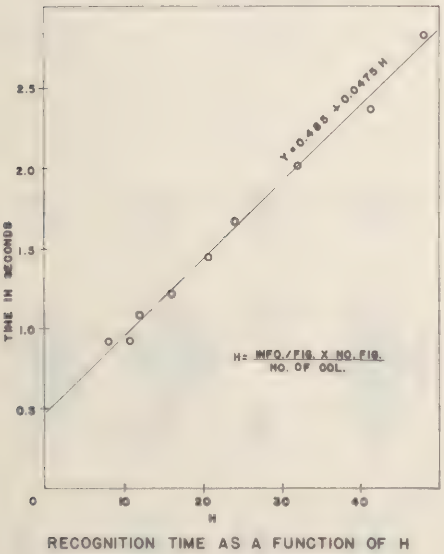

Figure 5. Recognition time as a function of H.

Several methods for predicting recognition times for all the conditions of this experiment were tried. One method was to plot sorting time against the total amount of information contained in all figures of a row (i.e., figure complexity x number of figures per row). This method of plotting did not result in a single function. However, when the amount of information per detail of a given figure (i.e., $\log_2$ of the number of categories of amplitude) was multiplied by the number of figures per row and plotted against time, the result shown in Figure 5 was achieved. It will be seen that a single straight line fits all the data closely.

Since the matrix used to generate figures was symmetrical, the same result as shown in Figure 5 would be obtained by plotting recognition time against the product of the number of figures times the log of the number of details in each figure. Although there was no rational basis for the latter treatment of the data, nevertheless it is not possible to test whether recognition time is a function of

(a) the complexity of single details or of (b) the number of details. Further experiments are being conducted by Mr. Weinstein to answer this question.[10]

Redundancy. — In experiments to date redundancy has been studied only with constrained figures, i.e., with figures sampled without replacement and having equal area. Three types of redundancy employed with such figures are illustrated in Figure 6. The lower left-hand figure is asymmetrical and constrained. In the lower middle and right-hand figures redundancy has been increased by doubling the number of categories available for determining the height of each figure detail, and by constructing identical figures in the top and in the bottom halves of each matrix. The bottom half of each constrained symmetrical figure is the mirror image of the top half. In the constrained reciprocal figure the bottom half of each bar is the reciprocal of the top half, so that the bottom and top contours are identical rather than mirror images.

The results of an experiment using these figures are shown in Figure 6, expressed as the average time in seconds to sort each type of figure from among a homogeneous subset of eight figures. The important aspect of this finding is that one method of increasing the redundancy of the figures was beneficial and the other method was detrimental. The fact that symmetrical redundancy decreases recognition time is not surprising, since the special characteristics of symmetrical figures have been noted long ago. Also, in the earlier methodology study it was found that symmetrical figures were learned and identified more readily than were asymmetrical figures.

Orientation. — The effect of a 90° rotation of all figures was analyzed as a part of the preceding study. Orientation was found to be a significant variable, but the effect was large only in the case of the symmetrically redundant figure. In the latter case, as seen in Figure 7, the figure that is symmetrical around a vertical axis is significantly superior to a figure symmetrical around an horizontal axis.

This finding also is not particularly surprising although it has practical as well as theoretical importance. For one thing, most objects seen in everyday life, such as people, trees, etc., are bilaterally symmetrical around a vertical axis, and the eyes scan more frequently in a left-right direction than in any up-down direction. There may also be a biological basis for the effect. The visual field has a greater horizontal extent, and the visual system itself is replicated bilaterally.

Random vs. constrained figures. — One of the factors that apparently produces a very large effect on recognition time is the difference between figures constructed by a random sampling process and by a process of sampling without replacement, i.e., the difference between the random and constrained figures illustrated at the top of Figure 6. We first became aware of this effect when we compared the sorting times of figures used in two different early studies, and we are now in the process of making

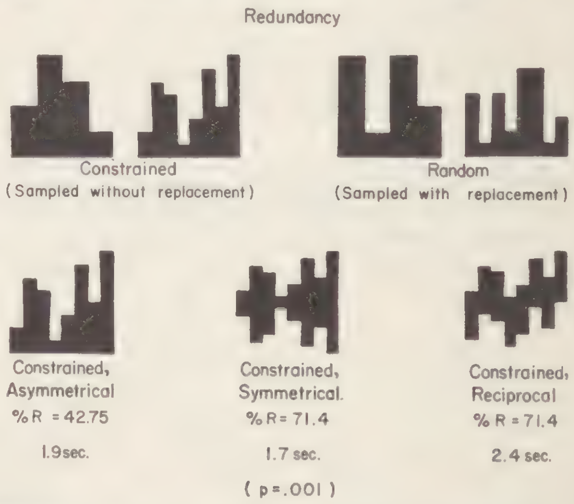

Figure 6. Three types of redundant figures.

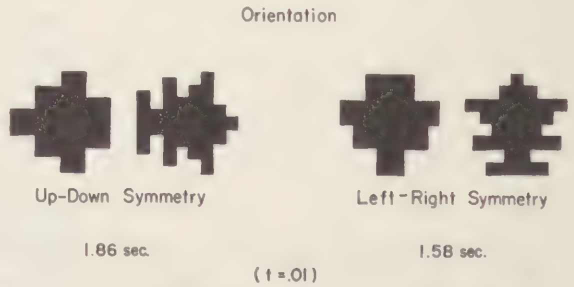

Figure 7. Average sorting time per figure for two orientations of the same symmetrical figures.

a direct comparison between these two types of figures. The difference in recognition time is of the order of magnitude of almost 2:1, the random figures being sorted the more rapidly. Considering only complexity, this finding, of course, is in direct contradiction to the previously reported results from varying the complexity of random, i.e., non-constrained, figures. In the study reported earlier the more complex figures were identified more slowly. In the present instance the random figure is more complex according to our criterion, since it is possible to generate many more random than constrained figures in the same matrix; however, the random figures are identified more quickly.

One possible explanation for this superiority may lie in the fact that the random figures vary in area, and area thus can be used as a cue for the identification of this type of figure. It is also possible, however, that there is something particularly detrimental about the type of redundancy present in the constrained figure. We are now attempting to identify more specifically the factor responsible for this difference. We hope that this line of study will throw some light on the question of what aspects or cues present in a figure are most easily used to identify it.

Use of redundancy to combat noise.—One of the most important practical problems in the design of all types of displays is the problem of how to increase the probability that a particular message or stimulus pattern will be identified correctly in the presence of sources of perturbation. The term "perturbation" or "noise" will be used here strictly in the statistical sense and is defined as any source that introduces a probability that a visual pattern will be modified. In practical situations various types of visual noise may be encountered. Traffic signs, for example, may be difficult to recognize because they blend into a background of similar shapes and colors, or they may be partially obscured by other objects or by shadows. In electronic systems, such as facsimili and teletype, noise may change a symbol or partially blot it out. In sonar and radar noise of many kinds may be encountered.

Shannon and others have dealt extensively with the problem of optimum coding of messages for transmission in the presence of noise. Such coding generally involves the use of redundancy. Accordingly, in his initial investigation[9] Rappaport studied the effect of different levels of redundancy in the presence of noise.

The type of noise chosen for study in our first experiment on this topic[9] was the probability that one of the white cells constituting the background for our figures would be changed into a black cell. The texture of the noise, i.e., its unit area, was in all cases the same as the unit areas used in constructing the figure itself.

Several steps of redundancy are shown in Figure 8. In the bottom row are eight constrained, asymmetrical figures of equal area. They are about 43% redundant. In the next row above, each of these figures has been made symmetrical and as a result redundancy has been increased to about 71%. In the next row the symmetrical figure has been replicated so that not only the left and right sides, but also the top and bottom halves, are identical. Redundancy is now 86%. Total area has been held constant, but note that the width of a detail is one-half what it was at the next lower step of redundancy. The top row of figures are 93% redundant.

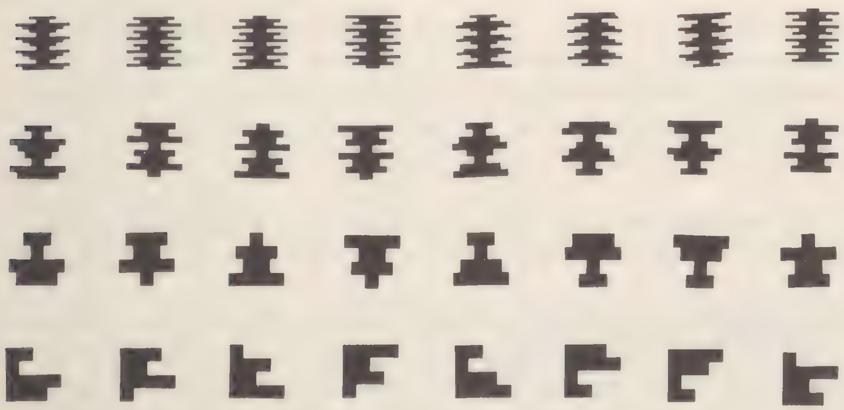

Figure 8. Figures of progressively greater redundancy.

Some of the figures appear to change markedly in the step from 71% to 86% redundancy, since the bars making up the pattern are often perceived as forming new groupings with this degree of repetition.

The first experiment of this series examined the effect of added redundancy alone in the absence of noise. Results are shown in Figure 9 for two different samples of figures. Redundancy above 81% becomes detrimental to rapid recognition. Mean recognition time per figure increases from 1.8 sec. at 71% to 2.4 sec. for 93% redundancy.

It was thought that some of the loss of speed for highly redundant figures might be due to smaller size of details.

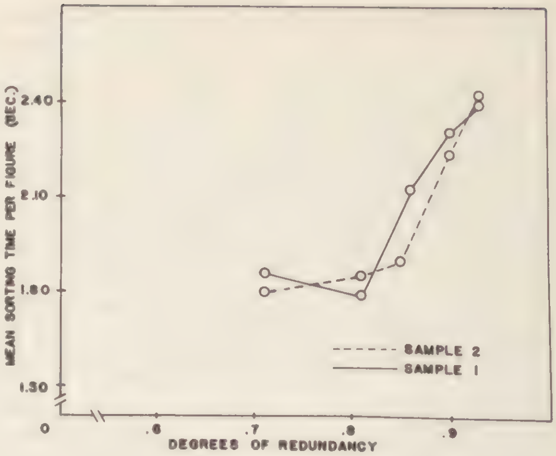

Figure 9. Sorting time per figure as a function of redundancy.


Figure 10. Figures used to compare effect of reduction in detail size.

This hypothesis was examined by means of figures of the two types shown in Figure 10. The 71% redundant figure was made smaller, in steps corresponding to the decrease in size accompanying three steps of redundancy.

Results of comparing these two types of figures are shown in Figure 11. For corresponding size of detail none of the pairs of points differ significantly, i.e., reducing detail size of a figure produces the same effect as making it more redundant. It can be concluded, therefore, that the loss of recognition speed above 81% redundancy is the result of loss of legibility due to small detail size. (At 81% redundancy the width of each detail is 3.3 mm.).

The next step was to determine recognition time in the presence of background noise as a function of redundancy. Examples of redundant figures in noise are shown in Figure 12.

Experimental results for the recognition of such figures are given in Figure 13. Both time and error curves are shown in the figure. Contrary to the previous results for the noiseless case, and in line with our predictions, additional redundancy now appears to have a beneficial effect, even out to 93% redundancy. In the presence of noise the 93% redundant figures had the fastest absolute sorting time and the fewest errors, even though they were sorted most slowly in the noiseless case. Conversely, the 43% redundant figures are sorted significantly slower

than any of the other figures in the presence of noise. The slight increase in time for the 86% figures over the 93% figures apparently is a real effect, and may be related to the regrouping effect noted earlier in going from 71% to 86% redundancy.

These results from the study of the use of redundancy to combat noise appear promising. A great deal of work will have to be done in this area, however, before we can recommend the best way of introducing redundancy, and the optimum amount of redundancy, to combat various types of noise. An important extension of research in this area will be relation of our results to the general problem of constancy.

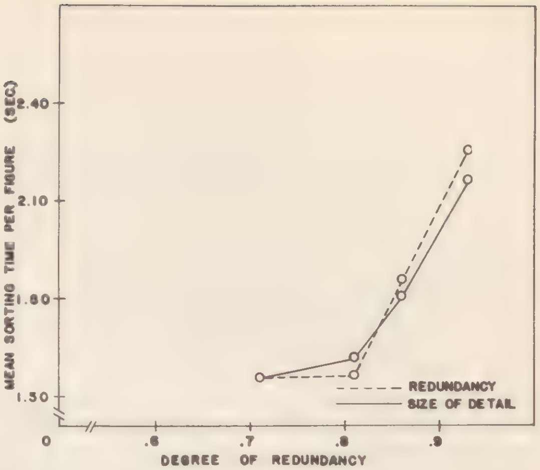

Figure 11. Sorting time as a function of size of detail, compared with the mean of the two samples shown in Figure 9.

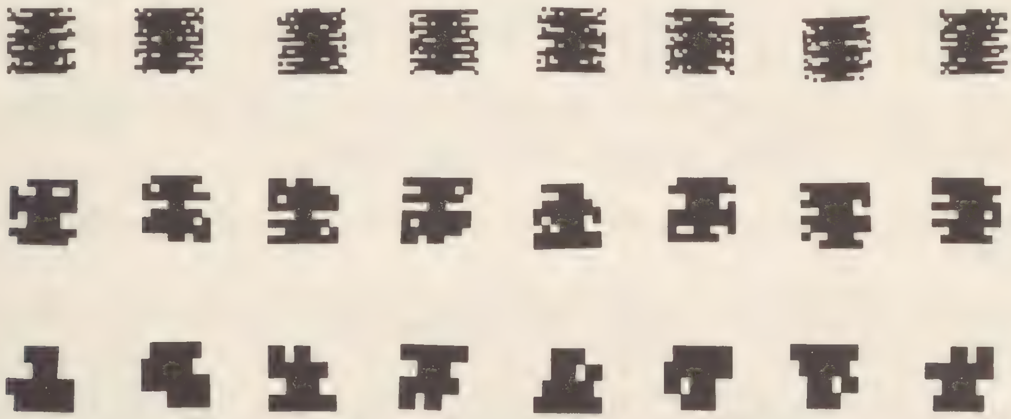

Figure 12. Figures of three levels of redundancy with 30% noise superimposed on the white background.

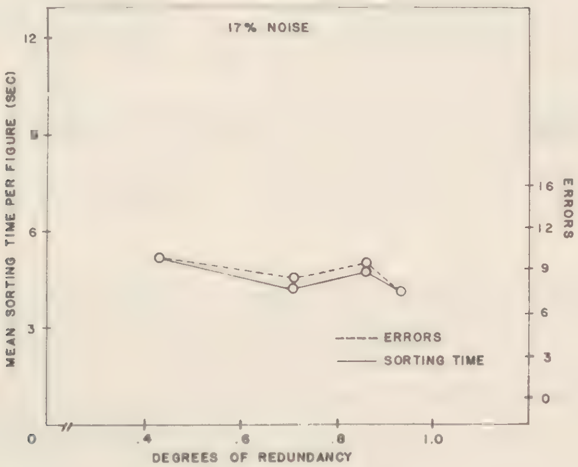

Figure 13. Sorting time per figure as a function of redundancy when figures are seen against a noisy background.

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INVESTIGATION OF MESOPIC MEASURES INVOLVED IN NIGHT VISION TESTING AND FIELD PERFORMANCE VALIDATION*

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In the Minutes and Proceedings of the 31st Meeting of the Armed Forces--NRC Vision Committee, November 1952, a research program plan and progress to that date was reported.[1] At that time the program plan involved the following major steps:

1. Development of an optical instrument suitable for visual measurement under mesopic levels of illumination.

2. Development of appropriate targets for this instrument.

3. Standardization of the procedure of test administration.

4. Development of an acceptable criterion for a validation study.

5. Determination of the validity of the mesopic measures against this criterion.

In the present paper is reported the progress made on each of the above steps. In addition, the results of a factor analysis of visual measures are related to other findings in this research program. Details of the several studies completed under this program are reported elsewhere.[2] Again, it is a pleasure to acknowledge the advice and guidance of the working group, selected from the Vision Committee, consisting of Dr. H. Richard Blackwell, Dr. Louise Sloan, Dr. Austin Riesen, and Dr. Parker Johnson, Chairman.

I. THE DEVELOPMENT OF TEST APPARATUS SUITABLE FOR MESOPIC VISUAL MEASUREMENT

The Armed Forces Vision Tester (AFVT) was modified to make the instrument suitable for mesopic testing. The modifications were planned by Dr. Blackwell (U.S. Army Contract DA-49-003-OSA-484) and the construction of the modified instrument was directed by him. In the field study described in Section V, the predictor tests were all presented in the modified AFVT.

A diagram of the modified AFVT is shown in Figure 1, together with technical details of construction. The specific objectives of the modifications were:

1. To provide for constant brightness at any specified luminance levels by eliminating the effects of line voltage fluctuations.

2. To make the target field uniformly bright over its entire surface at any light level.

3. To provide controls for varying light level throughout the mesopic-scotopic range.

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*The contents of this paper reflect the opinions of the author and do not necessarily represent the viewpoint of the Department of the Army.

4. To provide a means for field calibration of light level.

5. To reduce the standard illumination level to 12.0 foot-lamberts (10.11 log micro micro lamberts) specified for Armed Forces Testing.

The modified AFVT proved satisfactory in practice. Minor operating difficulties proved to be correctable in the field (lens fogging, light leaks, etc.).

II. DEVELOPMENT OF APPROPRIATE TARGETS

The second phase of the research program was the development of targets to be used in the validation study. A mesopic test, presented in an optical instrument, was to be developed for predicting ability to see at night under field conditions. According to previous analysis research, at least two important factors are involved in mesopic vision—resolution and brightness discrimination. Hence, targets were selected that were thought to contain one or the other factor or a combination of both. Each of the following steps in the development of the test targets constituted a separate research project:

1. Selection of appropriate targets for use in the test instrument.

2. Determination of optimum dark adaptation time for mesopic testing.

3. Development of a suitable field course to serve as a criterion.

4. Validation of the mesopic test against the criterion.

The findings in the first project are reported in PRB Research Notes 10, 14, and 15. Five target types were selected for preliminary tryout before the actual field validation:

1. A letter test based on the Snellen Wall Chart.

2. A modified Landolt ring test.

3. A line resolution test.

4. A chevron-shaped brightness discrimination test.

5. A circular-spot brightness discrimination test.

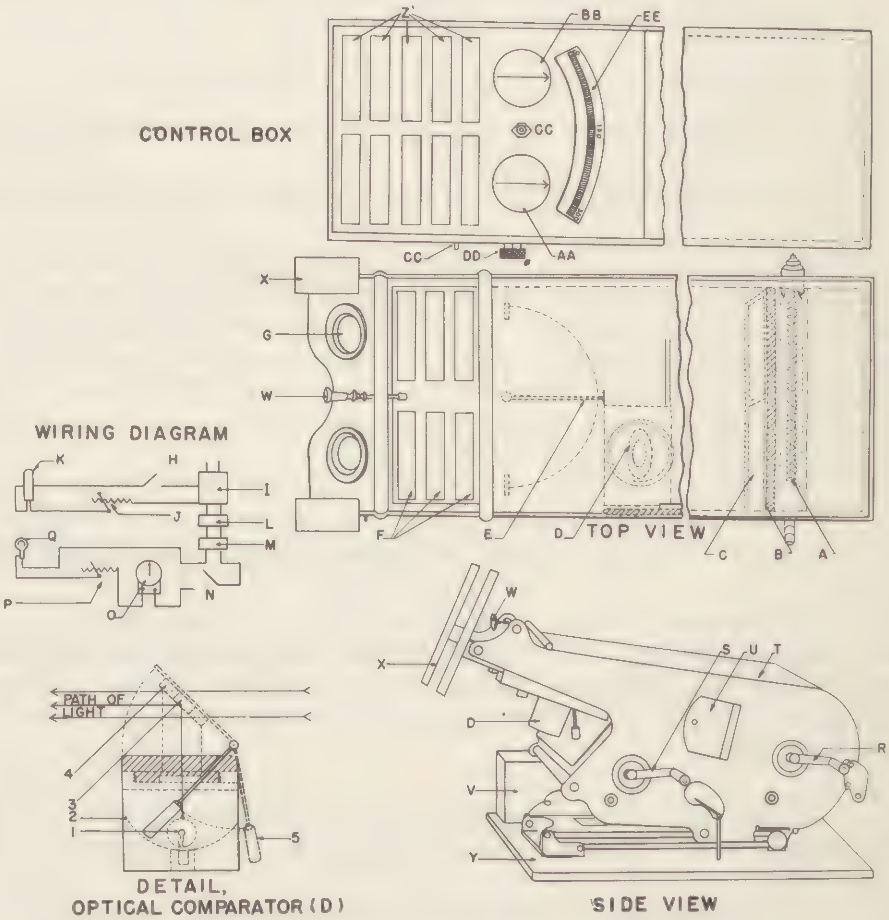

Figure 1. Modified Armed Forces Vision Tester.

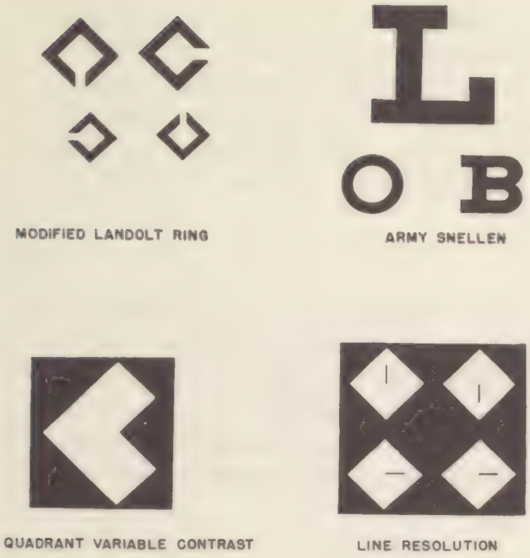

Figure 2. Sample targets.

Sample targets from these tests are shown in Figure 2.

These targets were presented in the modified Armed Forces Vision Tester at an optically-simulated distance of 20 feet. For comparative reference, the letter and Landolt ring tests were also presented as wall charts. Illumination was at 6.67 log micro micro lamberts. Subjects were 208 soldiers in the last week of advanced training at Fort Belvoir. After pre-adaptation to ordinary room lighting, the subjects dark adapted for ten minutes. Each subject was retested after a lapse of 24 hours.

The circular-spot test was immediately discarded when all subjects in the first two days of testing achieved perfect scores. With modification to make the items more difficult, it might, however, be a useful test. For the other four tests, 24-hour test-retest reliability coefficients were computed, along with intercorrelations, means, and standard deviations.

An examination of data suggested at the time that the most useful basis for choosing tests would be the reliability coefficients, inasmuch as score distributions for all four tests appeared to be about equally satisfactory. Accordingly, the Mesopic Letter Test and the Mesopic Line Resolution Test were selected for the validation study. It appeared wise to add photopic letter and scotopic modified Landolt ring tests for reference purposes.

Unfortunately, the targets which involve a considerable brightness discrimination factor did not have adequate psychometric characteristics except the Mesopic Line Resolution Test. This test requires more brightness discrimination than letter and Landolt targets but less brightness discrimination than the chevron contrast target. From the factor analytic point-of view, then, the line resolution target could be hypothesized as more promising than letter or Landolt targets provided the criterion also contains a substantial amount of brightness discrimination variance rather than a major requirement for resolving detail.

III. STANDARDIZATION OF TEST PROCEDURE

A. Determination of Optimum Dark Adaptation Time

One objective of the research program was the reduction in adaptation time which would be possible if a mesopic rather than a scotopic test were used. The study which determined the adaptation time necessary for reliable testing is reported in PRB Technical Research Note 25.

One hundred soldiers between the ages of 19 and 25 years were first pre-adapted to a photopic level of illumination so that all subjects would begin the experiment at reasonably the same level of visual adaptation. The men were then tested at a mesopic level of illumination (6.67 log $\mu\mu$L) on the Modified Landolt Ring Mesopic Test (a measure of retinal resolution) and on the Chevron Contrast Mesopic Test (a measure of brightness-contrast sensitivity). Score readings were taken every thirty seconds during the ten-minute period of testing while the subject was continuing to dark adapt to the target level of illumination. Twenty of the men were retested five weeks later.

There was a relatively rapid drop in threshold during the first three or four minutes of adaptation to the mesopic test level. After five minutes of adapation, the average threshold continued to drop, but more slowly, and began to approach a terminal value by ten minutes of dark adaptation. The gain in test performance from five to ten minutes was not sufficient to increase the average score by as much as one line of targets on the test. Examples of the types of curves obtained are given in Figures 3, 4, and 5.

B. Factor Analysis of Visual Measures

In addition to determining the appropriate dark adaptation time for the test variables, a factor analysis was made* of these same variables (PRB Technical Research Note 40). It so happened that the factor analysis was not quite complete when the outdoor criterion run (to determine the validity of the test variables) was performed. This is considered a bit unfortunate; in the absence of the completed factor analysis, it was not fully appreciated how important it would be to modify the chevron contrast targets so as to be adequate psychometrically for inclusion in the validation study.

In the factor analysis study one hundred soldiers were tested at intervals (1, 5, 10, 20, and 30 min.) while dark adapting to scotopic, mesopic, and photopic levels. The test targets and testing procedures were the same as in the dark adaptation study just described. A principal-axes factor technique was used to factor the 35-variable intercorrelation matrix. After 19 rotations of the factor matrix, an orthogonal sample structure was found. Eight factors were isolated.

Four of the factors accounted for about 80% of the common-factor variance. The Rod-Adapted Resolution Factor was identified as the ability to resolve fine detail at scotopic and mesopic luminances after a sufficient period of dark adaptation. The Rod-Adapted Brightness Discrimination Factor was identified as the ability to discriminate differences in the brightness of relatively large areas at scotopic and mesopic luminances after a sufficient period of dark adaptation. Similar resolution and brightness discrimination factors were identified for the cones but at mesopic or low photopic luminances requiring less adaptation time. The four minor factors were tentatively identified as glare recovery, a cognitive or experimental factor, form perception, and a perceptual speed factor. In Table I are shown the factor loadings on 12 selected test variables from the total of 35 variables. Without making any distinctions between targets and considering only the four important factors (I through IV), as level of illumination changes from scotopic to photopic, there is in general a progressive decrease in the Rod-Adapted Resolution Factor and in the Rod-Adapted Brightness Discrimination Factor but a progressive increase in the Cone-Adapted Resolution Factor and some increase in the Cone-Adapted Brightness Discrimination Factor.

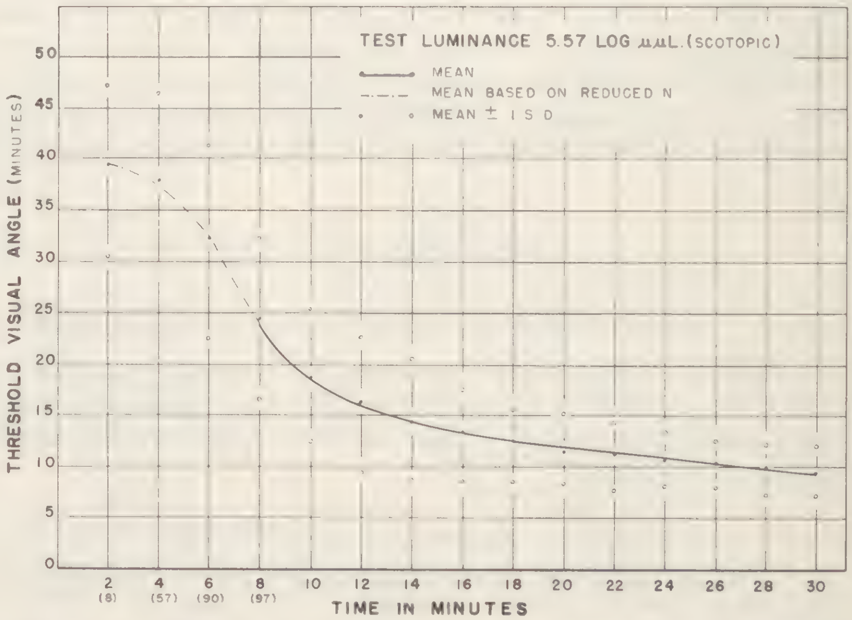

Figure 3. Modified Landolt Ring threshold means and standard deviations during dark adaptation to 5.57 log $\mu\mu$ L. after five minutes pre-adaptation to 753 mL. (N = 100, exceptions noted in parentheses under time).

*The factor analysis was designed and completed by Dr. Joseph Zeidner of the Personnel Research Branch, TAGO.

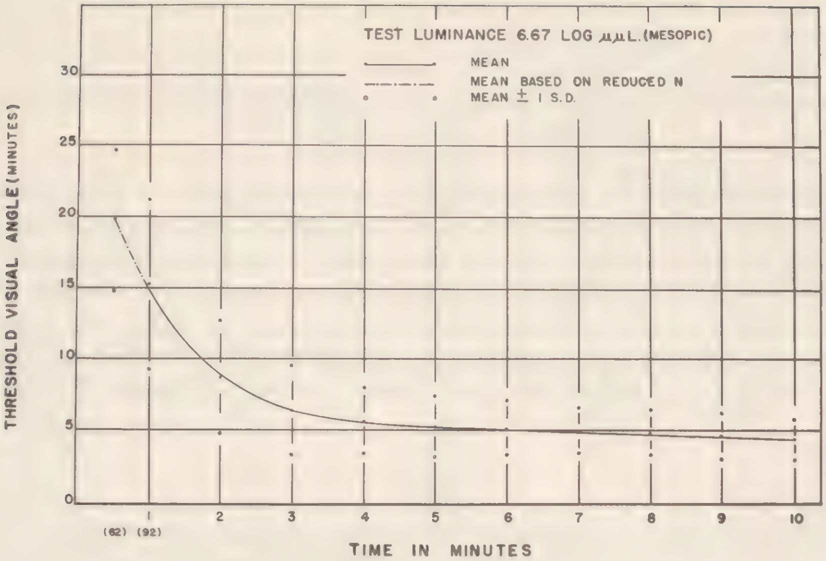

Figure 4. Modified Landolt Ring threshold means and standard deviations during dark adaptation to 6.67 log $\mu\mu$ L. after five minutes pre-adaptation to 753 mL. (N = 100).

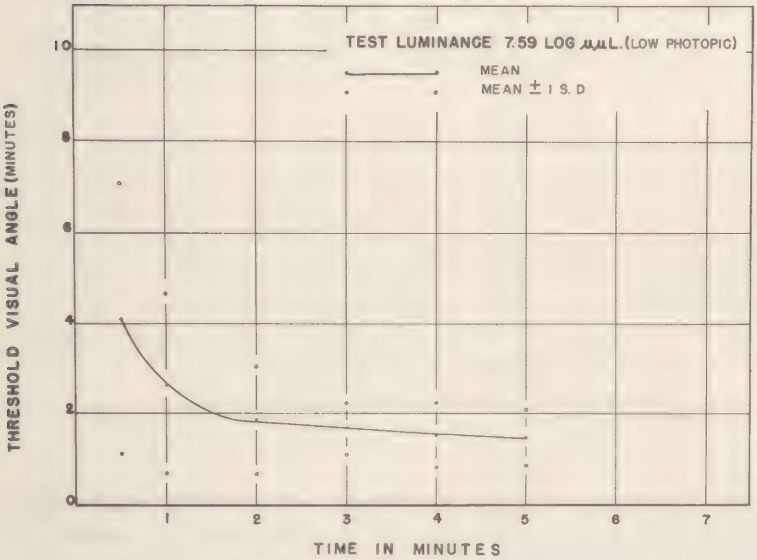

Figure 5. Modified Landolt Ring threshold means and standard deviations during dark adaptation to 7.59 log $\mu\mu$ L. after five minutes pre-adaptation to 753 mL. (N = 100).

Combining the rod factors and the cone factors and then the resolution factors and the brightness discrimination factors, the per cent of variance accounted for by these combinations is shown in Table II for six selected sets of experimental conditions. In mesopic luminance, the Modified Landolt contributes only 10% brightness discrimination variance, whereas the Chevron Contrast Test contributes 56%. Similarly, the Modified Landolt contributes only 15% to the rod factor variance, whereas the Chevron Contrast contributes 56%. Hence, the desirability of having a substantial amount of brightness discrimination variance represented when the criterion involves visual performance other than ability to resolve fine detail in mesopic luminance. Later, (in Table IV) the validity coefficients of the visual test will be shown in relation to factor composition.

IV. DEVELOPMENT OF AN OUTDOOR CRITERION

For this part of the program, a fortunate coincidence of research effort occurred. The Human Resources Research Office (HumRRO) of George Washington University, at the direction of the Assistant Chief of Staff, G-1, was making a study of the following:

1. The effect of prior basic training or combat experience on ability to see at night.

2. The usefulness of a method for training to shoot at night where ability to see the target almost guaranteed ability to hit it.

Thus, HumRRO and PRB had a common requirement for the construction of a night field-detection course.

Such a course was laid out on a range in the "Alabama" area of Fort Benning. The ground was very flat, and an unbroken row of trees on the far side of the course provided a background. It was divided into six parallel lanes, each 15 feet wide, with a 20-foot separation between lanes. Distance markers at 5-yard intervals bordered the left boundary of each lane. The 15-foot width of the lanes allowed eight soldiers to observe simultaneously (or on all six lanes, usually forty-eight soldiers in all). Burlap screens 4x6 feet in size provided "booths" separating the observers from one another. The general layout of this criterion course is shown in Figure 6.

Table I

FACTORIAL COMPOSITION OF SELECTED LANDOLT AND CHEVRON TARGET TESTS

FACTOR	Scotopic: 5.57*				Mesopic: 6.67*				Low Photopic: 7.59*			
	20'		30'		5'		10'		1'		5'	
	C	Ch	C	Ch	C	Ch	C	Ch	C	Ch	C	Ch
I. Rod Resol.	80	40	63	28	41	05	38	28	20	18	14	03
II. Rod B.D.	35	73	32	75	20	58	12	69	18	31	10	43
III. Cone Resol.	13	12	36	32	67	33	71	31	65	57	81	57
IV. Cone B.D.	14	21	20	12	38	56	30	29	14	31	-02	21
V. Cognitive	-02	-11	-10	-04	-16	07	-13	06	21	09	-05	01
VI. Form Perc.	03	06	03	-02	03	-11	03	-18	14	-03	42	-23
VII. Glare Recov.	-27	-12	-28	-20	-07	-03	-12	-10	09	05	-05	-08
VIII. Perc. Speed	03	13	-14	07	-14	-07	-08	02	27	13	-08	30
Communality	87	80	78	79	85	78	79	78	65	58	86	70

* Log micro micro Lamberts (N = 100) Decimals omitted

Abbreviations: B.D. - Brightness Discrimination, C - Modified Landolt, Ch - Chevron Contrast

The "targets" were human "aggressors." When observations were not actually taking place, the aggressors were hidden behind screens in the lane; three aggressors were used for each lane, and there were three screens at distances of 15, 25 and 40 yards from the observers. The distances were varied to suit the illumination prevailing; the intention was to compensate for the effect on criterion scores of variation in illumination (see Section V for compensating procedure).

A total of 66 problems constituted the course. A problem called for an aggressor to come from behind a screen and assume a posture—standing, kneeling, or prone. The sequence of postures had been randomized beforehand; each of the three aggressors in each lane had a list of about 1/3 of the problems. As a check some of the problems required the aggressor to remain behind the screen—to be "absent." Each aggressor was dressed in fatigues and wore a fatigue cap. They were provided with red flashlights to enable them to consult their problem-lists while behind their screens without beeing seen by the observers.

One umpire served each lane, that is, monitored a maximum of eight observers. All six lanes were monitored from a central control point from which all commands were given by loud-speaker.

Table II

PER CENT OF VARIANCE ACCOUNTED FOR BY ROD AND CONE FACTORS IN SELECTED SETS OF EXPERIMENTAL CONDITIONS (ILLUMINATION X TARGETS)

Factor	Scotopic 30'	Mesopic 10'	Low Photopic 5'	Target
I and II Rod	51	15	03	Mod. Landolt
III and IV Cone	17	59	66	
I and II Rod	64	56	18	Chev. Contrast
III and IV Cone	11	18	36	
I and III Res.	54	64	68	Mod. Landolt
II and IV B.D.	14	10	01	
I and III Res.	18	18	32	Chev. Contrast
II and IV B.D.	57	56	22	

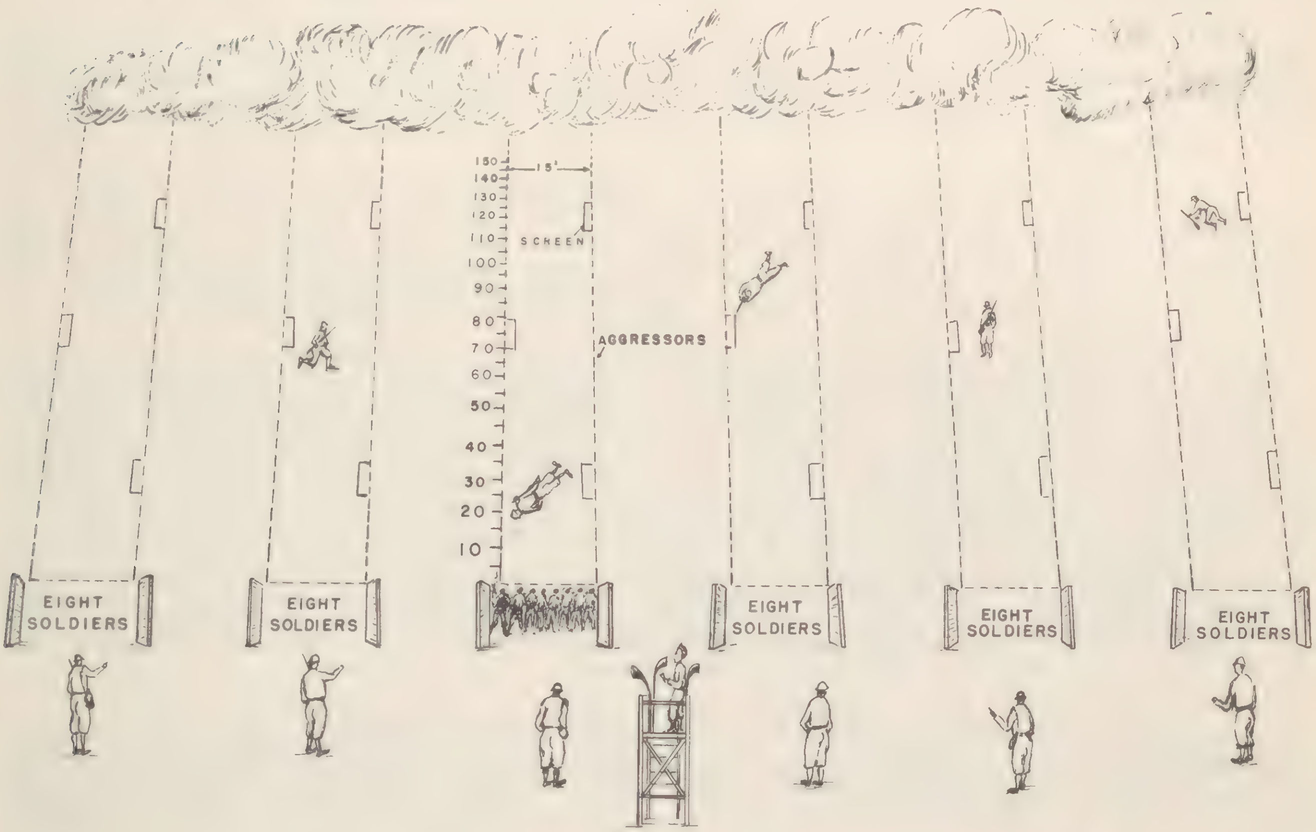

Figure 6. Courses at Fort Benning, Georgia on which criterion data were gathered under conditions of night illumination in the validation study of Mesopic Vision Tests.

V. FIELD STUDY OF THE MESOPIC MEASURES

A. Procedure

At the start of any given criterion run in the validation study, the men were lined up, one to a "booth", eight to a lane, facing away from the aggressors and toward the central control point. The instructions were then read to all men. Each man was furnished with a pad of paper. He was to indicate his response by writing a single letter after each problem number on the paper: S for standing, K for kneeling, P for prone, and N for nothing.

At the command, "Set up Problem 1", the appropriate aggressors assumed the positions indicated on their lists, while the observers wrote "1", in the proper place on their pads. When the indicated actions were completed, an aggressor was at the proper distance and the proper position in each of the six lanes; the observers were awaiting the command to observe. At the command, "Observe Problem 1", the observers about-faced, assumed a prone posture with chins on chin-rests (3-inch high stakes) and tried to determine whether or not an aggressor was in the lane, and if so, in what position.

At the command, "Record Problem 1", the men arose, turned, and sat facing away from the aggressors. The entered on the pad the letters S, K, P, or N, depending on what they believed they had seen. The umpire then collected all of the slips of paper for Problem 1.

The command, "Set up Problem 2", initiated the next cycle, exactly as before; of course this time the aggressors were in a new position at a new distance (or absent). The procedure continued for all 66 problems. Usually, the complete run required about 1-1/4 hours. More than one group was run on a given night when the illumination allowed.

The schedule of the criterion runs (showing dates, times, illumination, and adjusted range) is given in Table III. Also included, for economy of space, are the mean and standard deviation of criterion scores. The first six of the runs involved different groups of men for each run. The 7th through 10th Runs were the retests from which criterion reliability was computed. Specifically, the men participating in Run 5 were retested once in Run 7 and again in Run 9. Similarly, Run 6 men were retested in Runs 8 and 10. The column "N", showing number of men in each run, does not specify the number retested, since some men were unavoidably "lost" and some "gained" during the course of the study. Although as many as 50 men could be tested at one time, the number actually tested was usually less. All in all, a total group of 256 soldiers were tested.

It was impractical to keep the natural illumination constant by testing only when the light was at some specified level. Consequently, opportunity to see had to be equalized by other means. The method used was to adjust the target distances (as indicated in Table III) so that the task of seeing was roughly equivalent even though the light varied. Thus, during Runs 1 through 4, when the moon was full or almost full, the targets ranged from 25 to 125 yards; they were about as easy (or as difficult) to see as during Runs 5 through 10 when the moon was new, and the targets ranged from 15 to 75 yards. The control of illumination during a run was impossible, since there was always slight variation in the natural illumination from moment to moment. In fact, Run 6 was "spoiled"; the run was administered on two different nights, and (as Table III indicates) for the first 37 problems the illumination was only 1/10 as great as in the final 29 problems.

Table III

DESCRIPTIVE INFORMATION ON CRITERION RUNS, INCLUDING ILLUMINATION, RANGES, AND SCORES

				RANGE			CRITERION	
Run	N	Date	Time	Foot-Candles*	Log Micro Micro Lamberts	Yards	Mean	Std. Deviation
1	50	28 Jul	2145-2235	.00110-.00270	6.08-6.46	25-125	30.2	6.5
2	49	28 Jul	2235-2315	.00270-.00312	6.46-6.52	25-125	32.3	6.6
3	46	28 Jul	2315-2400	.00312-.00562	6.52-6.78	25-125	33.9	5.6
4	38	28 Jul	2400-2445	.00622-.00700	6.83-6.88	25-125	32.8	6.3
5	41	19 Aug	2100-2210	.00028-.00046	5.47-5.69	15-75	34.1	8.1
6	36	19 Aug	2220-2300	.00006-.00025	4.81-5.42	15-75	36.8	9.9
	**	22 Aug	2000-2030	.00165-.00225	6.25-6.38	15-75		
7	41	20 Aug	2015-2100	.00422-.00620	6.66-6.82	15-75	56.0	8.1
8	37	20 Aug	2110-2200	.00422-.00505	6.66-6.74	15-75	55.7	6.7
9	40	22 Aug	2030-2130	.00210-.00225	6.35-6.38	15-75	50.4	8.7
10	32	22 Aug	2130-2230	.00210-.00270	6.35-6.46	15-75	52.1	8.1

*Measurements made perpendicular to glossy white photographic paper placed on the ground, using a Taylor Low Brightness Meter.

**Run 6 could not be completed in a single night.

B. Validity of the Mesopic Measures

Validity coefficients are presented in Table IV. According to the coefficients for the total group, the most effective targets are the Mesopic Line Resolution Test and the Scotopic Landolt Ring Test in predicting the night criterion. The adjusted validity coefficient of the Mesopic Line Resolution Test is .51. This is substantial validity for predictive purposes. Relative effectiveness is more clearly demonstrated on the Run 9 group that was retested twice and most carefully controlled. Here, the Mesopic Line Resolution Test is clearly the most valid (uncorrected validity of .55 and adjusted validity of .83). These validity findings are consistent with the factorial composition of the variables—the Mesopic Line Resolution Test involves more brightness discrimination than either the letter or the modified Landolt ring targets (the only other targets used in this validity study).

From the present study, it appears that the Mesopic Line Resolution Test is the best choice for predicting the outdoor criterion. It is possible, however, that an improved chevron contrast test would add considerably to the predictive efficiency of the Mesopic Line Resolution Test.

Table IV

VALIDITY COEFFICIENTS OF FOUR SELECTED TESTS AGAINST THE NIGHT FIELD DETECTION CRITERION

Total Group N = 256
Run 9 Group N = 40

Variable and Comment on Factors	Validity Coefficients			
	Total	Adjusted	Special	Adjusted*
1. Photopic Letter Similar to Landolt	.28	(.41)	.17	(.25)
2. Mesopic Letter - 10' Similar to Landolt	.21	(.31)	.40	(.60)
3. Mesopic Line - 10' More resol. than chev.; less B.D. than Chev.; more B.D. than letters or Landolt. 77% resol., 10% B.D. (PRS Report No. 742)	.35	(.51)	.55	(.83)
4. Scotopic Ring - 30' 69% resol., 7% B.D. (from Low Brightness Factor Study)	.36	(.52)	.36	(.54)

* Adjusted for unreliability of criterion only (reliability of the criterion was .46).

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2. PRB Technical Research Reports 816, 831, 858, 942, 963, 974, 975; PRB Technical Research Notes 10, 14, 15, 25, 40.

ILLUMINATION OF VISUAL ACUITY CHARTS

Louise L. Sloan, Ph.D.

and

Lawrence T. Odland, Capt., USAF (MC)

For several years working groups of the Vision Committee have concerned themselves with problems pertaining to the improvement and standardization of procedures for measuring visual acuity. In 1947 a Manual of Instructions for Testing Acuity was distributed, which included specifications for a system of illumination. This is a permanent installation of three 200-watt ceiling lights designed to give an illumination on the chart of 12-18 foot-candles, i.e., 15 foot-candles $\pm$20%. The Manual does not say whether these tolerances define the permissable range of illumination at any one time, or also include changes with voltage fluctuations and with aging of the lamps.

A working group also developed a test chart, the numerous revisions of which have been reported at almost every meeting since 1947. An important feature of this chart is that the same ten letters in a different order are used to measure acuity at all except the two lowest levels. For subjective determinations of refractive error the ten letters provide a balanced assortment of vertical, horizontal, oblique and curved contours. Because of the size of the chart (about 2x2 feet) it was expected that its adoption would require the use of the overhead lighting system, and would eliminate the use of commercial lighting cabinets. In the latter, the illumination differs widely in different areas and is usually well above the recommended range.

Other members of the Vision Committee who are interested in the adoption and procurement of standardized acuity charts have objected to the permanent lighting installation as impractical and have proposed that the chart used for clinical testing be modified so as to fit the various lighting cabinets now in use.

I should like first to discuss the objections to both proposals, and secondly, to suggest two possible lighting schemes in the hope that one or the other would satisfy both groups. We measured the illuminations provided by different representative commercial lighting cabinets manufactured by Meyrowitz and by Bausch & Lomb. The first is lighted by a single fluorescent tube mounted between the two charts, and is equipped with mirrors at the sides, top and bottom to distribute the light. Earlier versions used a Lumiline lamp. This unit is used at the Wilmer Institute, at Walter Reed Army Hospital and probably in many other places. According to the catalog it provides a uniform illumination of 10 foot-candles. Measurements of our most recently acquired unit showed that the illumination actually varied in different areas from 20 to 150 foot-candles. We wrote to the manufacturer about the discrepancy. Excerpts from his reply were as follow:

> "The man who wrote the description of our Test Cabinet is no longer with the concern and we cannot question him regarding the illumination. However, we believe he made an accurate test at the time. We have sold a great many of these cabinets and have never had any complaints concerning the illumination. It seems to us to be very bright

and evenly diffused. This cabinet was purchased by you two years ago and it is possible that the lamp may need replacement."

A second unit, also in use at the Wilmer Institute, takes four incandescent lamps. Two are mounted on each side of the chart in projecting metal shields. With four 25-watt bulbs the illumination ranged from about 16 to 38 foot-candles on different areas of the chart. This exceeds the specified 12-18 ft. candle limits. The illumination would be still greater if 25-watt lamps had not been substituted for the 50-watt bulbs supplied with the unit.

We also measured the illumination provided by three 200-watt lamps installed at the locations specified in the Manual. With a line voltage of 115 the illumination varied from 22 foot-candles at the top to 12.5 at the bottom. This is a little greater than the specified range of 12-18 foot-candles. A decrease in illumination from top to bottom of the chart would be expected because of the increase in distance from the light source and the increase in angle of incidence of the light. A practical objection to this lighting system is that, once installed, it is not easily moved to another location. Purchase of a lighting cabinet by number from a catalog is, moreover, simpler than seeing that the electrician installs lights at the proper height and proper distances from the chart, and provides reflectors to eliminate glare.

Figure 1

We have built an inexpensive lighting fixture which can be used with the two-foot square chart. Its general construction is shown in Figure 1. Fluorescent tubes are mounted in shields the interior surfaces of which are painted a dull black so that the amount of light incident on the chart is independent of any reflector. Strips of Plexi-glass are placed in front of each tube. The arms holding the lighting units can be folded inward or removed for transportation or crating. The distance of the light sources from the chart which gave the most uniform illumination was determined first by calculation, and finally by trial and error. At this distance Plexi-glass diffusers of different densities and thicknesses were tested until one was found which reduced the illumination to the desired level.

Figure 2 shows the illumination in foot-candles on different areas of the chart and its immediate surroundings. These foot-candle values are for a line voltage of 115.

A change of ±5 volts produces a change of about ±5% in illumination for fluorescent light sources, as contrasted with about ±15% for 200-watt incandescent lamps.

We also investigated the possibility of obtaining uniform illumination of the desired amount from a single portable fixture. A 300-watt lamp in a reflector, placed just to one side of the chart and at the same height gave an illumination of 12-14 ft. candles on the test chart when the light source was 6-1/2 feet from the chart. A variation in distances of ±6 inches had no significant effect on the amount of illumination incident on the chart. About the same level of illumination was obtained from two 24-inch 20-watt Daylight Fluorescent tubes mounted vertically at a distance of 45 inches from the chart. Because of the shorter distance the illumination was not as uniform in this case and varied from 12.5 to 18.5 foot-candles in different areas.

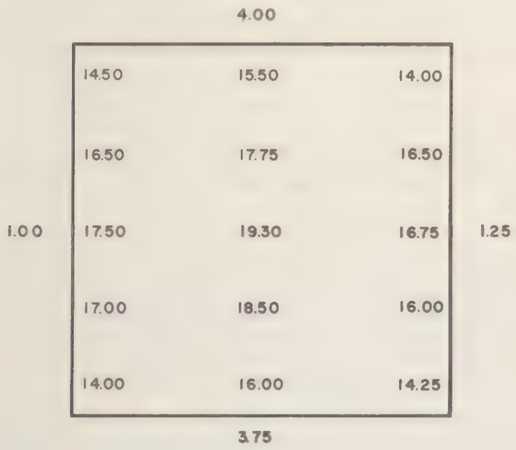

Figure 2

A single portable floor unit might be the ideal choice for a laboratory equipped to measure illumination, in order to determine the proper distance for any given unit. The other slightly more expensive equipment requires only the replacement of the fluorescent tubes at proper intervals. The possibility of installing the wrong type of tube in this particular unit is limited to the substitution of White for Daylight Tubes. This error would increase the illumination by about 15%. In a system using incandescent lamps the possibilities of substituting non-standard lamps are far greater.

Since the lighting cabinets now in use are highly unsatisfactory as regards both the level and the uniformity of illumination, it does not seem advisable to sacrifice the fundamental principles of the Armed Forces' Acuity Chart to made it fit such units. There are many ways of illuminating large charts, if rigid control of the amount of light is not considered necessary. Illumination within the specified ranges can be obtained by a lighting cabinet such as has been described, by a single portable fixture located at the proper distance from the chart, or by a fixed installation of overhead lights.

Discussion

Dr. Rose agreed that Dr. Sloan's lighting fixture and the illumination of visibility charts were highly satisfactory.

A VISION TESTER SUITABLE FOR MILITARY USE*

John H. King, Jr., Colonel, MC
William C. Owens, Captain, MC
John W. Sheridan, Lt. Colonel, MSC

The lack of a standard method for administering vision tests has been one of the primary difficulties of visual screening in the Armed Forces. The methods of vision testing used in the Services have varied greatly in different installations with resulting variations in the recorded visual scores. The Armed Forces—NRC Vision Committee has accomplished much in attempting to correct this situation.

The use of instruments which optically simulate distance aids in establishing uniform testing conditions. With such instruments the targets and illumination can be constant regardless of whether the vision tests are administered in a large general hospital or in a small induction station in some remote area of the country.

For the Armed Forces, vision testing instruments should have certain military characteristics. Among these are lightness, smallness, strength and portability. The targets used in a military instrument should be non-breakable and durable under all temperatures and atmospheric conditions. Likewise, the illumination should be constant and from bulbs that are readily available and easily replaceable in field situations.

The instruments presently available for vision testing are deficient in some of the military characteristics. For instance, they are too bulky and heavy. The glass plates used for the targets in some of the instruments are breakable. In addition, the presently available instruments do not have voltage regulators in their illuminating systems.

During the past two years the Ocular Research Unit has been attempting to develop a vision testing instrument that would fulfill the military requirements. It was also hoped that an instrument could be developed that would be less expensive than those presently available.

About a year and a half ago a Vision Rater was constructed and tested by the Ocular Research Unit. This instrument had the test charts photographed onto film mounted on a circular rotating disc. One disc of test material could be removed easily and replaced by another disc with different test material. This instrument was shown informally to the Working Group of the Armed Forces—NRC Vision Committee at the meeting held at Fort Knox during November, 1953. The original instrument still did not fulfill the required military characteristics. However, the principle employed seemed a good one. Numerous changes were made and "a description of" the new, more efficient instrument is presented in this paper. Our investigation has been divided into three parts. The first to be reported in this paper concerns the mechanical characteristics of the instrument. The second will be a validation of the new instrument against clinical tests and the third a validation against the Armed Forces Vision Tests. The second and third parts of the study will be reported at a later date.

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*From the Ocular Research Unit, Walter Reed Army Medical Center, Washington 12, D.C.

MECHANICAL CHARACTERISTICS

Size - The newly developed vision rater is considerably smaller than the present Armed Forces Vision Tester (Figure 1). When it is opened for use its maximum height is only 14-3/8 inches. The sides of the supporting base have slots so that both the height of the machine and its angular tilt can be adjusted. For packing and shipping, the machine is placed in the lowest position in the base (Figure 2). In this position its dimensions are only 15-3/4" x 9-3/8" x 8-1/2". This is a much more compact instrument than others presently available.

Weight - The new instrument itself weighs 18 pounds. Its stable supporting base has a weight of 10 pounds. At the present time the base is made of solid aluminum. In the future the base will be made of hollow aluminum which will further reduce its weight.

Strength - The new instrument is made of an aluminum alloy. The body is of welded construction. This is stronger than the use of separate molded parts united by screws. The targets are on photographic film laminated between plastic and are unbreakable.

Figure 1. New Vision Tester shown on left is small and light.

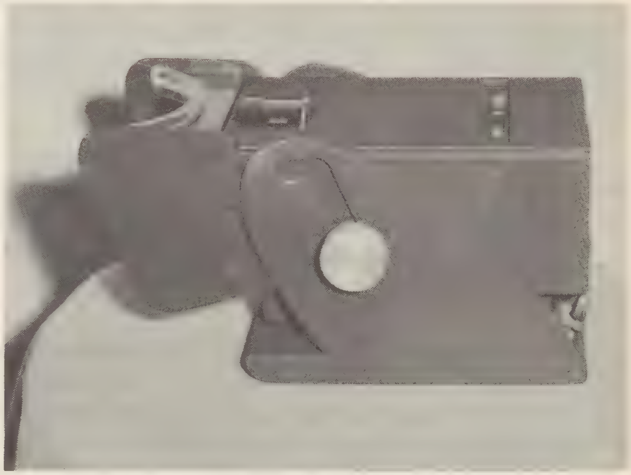

Figure 2. New Vision Tester prepared for shipment.

Ease of Operation - When used on a table, the base is employed. The adjustable slot in the sides gives a great variety of angles so that the tilt can be modified for whatever table or chair height is available (Figure 3).

The head of the examiner is shielded at the sides so that extraneous light from the examining room does not interfere. The side shields are far enough apart to accommodate people wearing extra-large spectacle frames.

The instrument can also be removed from its base and mounted on an adjustable tripod (Figure 4). This type of mounting is particularly useful when a survey is made with a large number of people. As the subjects pass through in a line, their vision can be tested while they are standing.

The headrest, using the new Negator spring, is a radical departure from those previously used. It is floating and slides up and down freely, automatically adjusting itself for each user (Figures 5 and 6). The curve in which the headrest travels has been designed to

Figure 3. New Vision Tester in operation.

Figure 4. Mounting on stand is useful for rapid mass testing.

conform with the average tilt of the head employed by users of bifocals. In the past, near vision testing on a machine has been awkward in subjects with bifocals. With the new automatic headrest, the head is easily and naturally placed in the proper position for use of the bifocal segments.

All of the designations on the targets and lenses are clearly marked. On the targets, the designations are placed on the laminating plastic. Enough light is transmitted through the plastic so that the examiner can read the designations in reduced room illumination. On the new machine the designation for right eye and left eye is clearly marked, thereby avoiding any confusion that might arise when using the occluder on the present vision testers.

Lenses - The new vision testing machine uses coated achromatic lenses which give sharper definition of the targets. The lenses are mounted in a single lens unit that fits into the body of the machine (Figure 7).

A variable prism for detecting malingerers on the muscle balance tests can be easily added to the instrument. This malingerer detecting device may be required for tests performed by certain areas of the Armed Forces such as the Air Force. Rotary prisms may be placed on the machine to measure the range of convergence and divergence if required for any particular Armed Forces installation.

Target - The targets in the new instrument are on photographic film instead of glass plates. The film is laminated between plastic discs mounted in an aluminum cartridge (Figure 8). The special Eastman photographic film used is not subject to significant changes with climatic or atmospheric conditions. Such targets are non-breakable and they can be cleaned very easily by rubbing a soft cloth over their surface. Cleaning the exposed glass plates in the present Armed Forces Vision Tester is more hazardous. The targets in the new machine are inexpensive and therefore easy to replace.

Figure 5. Automatically adjustable headrest.

Figure 6. Headrest floats up and down on negator spring.

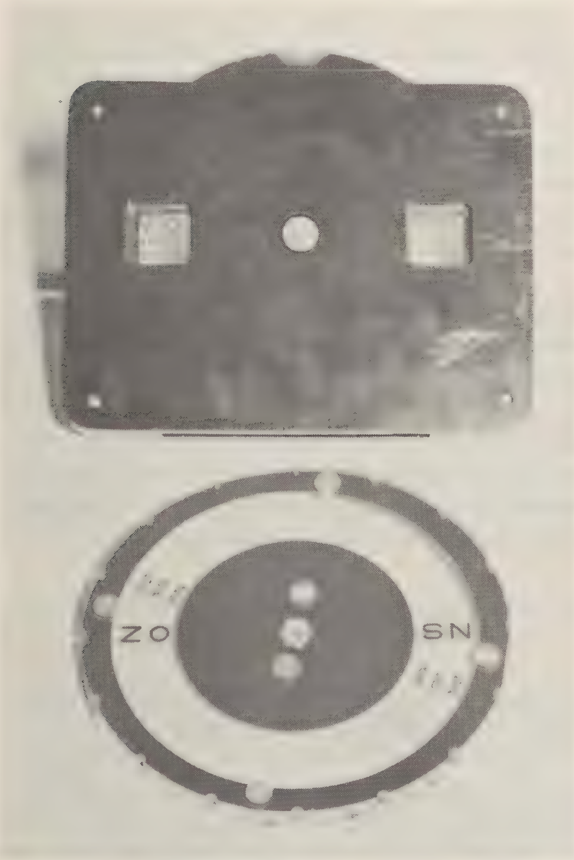

Figure 8. Targets are laminated between plastic and mounted in an aluminum cartridge.

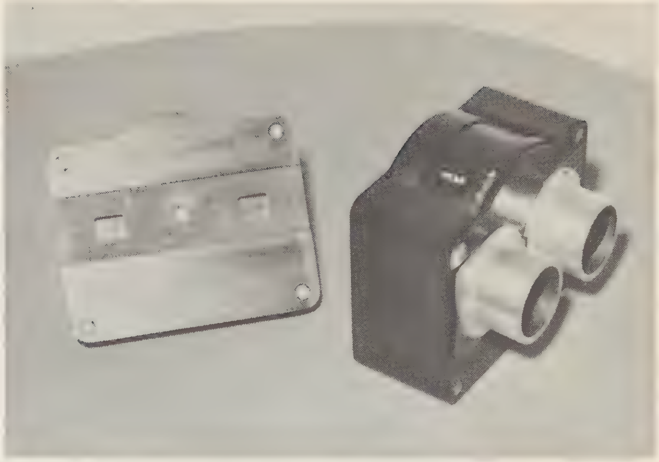

Figure 7. Target cartridge shown on left and lens battery shown on right.

The new machine uses a single set of plates for both distance and near. This simplifies the construction and increases the ease of operation. The targets used are those proposed by the Armed Forces—NRC Vision Committee. A line of letters at the visual acuity level of 20/10 has been added in addition to those found in the Armed Forces Vision Tester. Therefore, with the new machine, visual acuities better than 20/20 are divided into four categories.

The small cartridge containing the test material can be easily removed and another cartridge containing material for different tests inserted (Figure 9). In this way, the machine is very flexible. If a special test is required by any Armed Forces organization, the test material can be placed on a supplementary cartridge which is easily and quickly inserted into the machine. For instance, multiple pattern targets for testing visual fields could be employed.

Illumination - The new machine uses inexpensive 7-watt 115-125 volt Christmas tree bulbs instead of the more expensive Lumiline bulbs. These standard Christmas tree bulbs are not only less expensive, but are also readily available without any delay or trouble.

The new instrument has a voltage regulator. Dr. Louise Sloan Rowland had shown that the illumination from a 25-watt Lumiline frosted bulb varied with changes in the voltage input. She showed that if the illumination was reduced to 81.5% when the

Figure 9. Target cartridges can be easily changed.

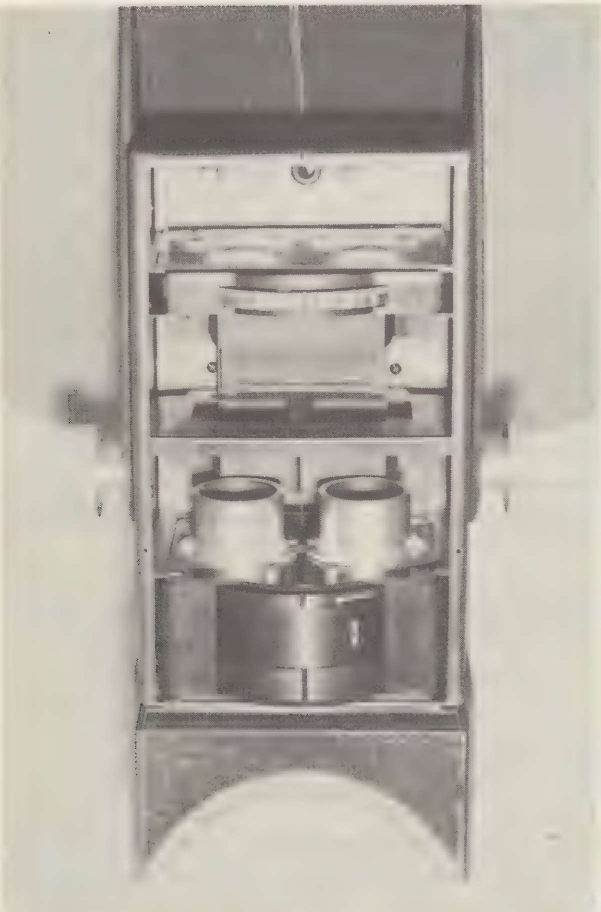

Figure 10. Top removed showing illuminating system, target cartridges, and lens battery.

voltage dropped to 110 volts. On the other hand, the illumination from the same Lumiline bulb increased to 118.4% when the voltage was increased to 120 volts. For these reasons it was thought desirable to use a voltage regulator in the new instrument (Figure 10).

The instrument also has a variable rheostat which can be adjusted to alter the amount of illumination present on the targets. Therefore, it can be used in special research laboratories where visual skill at reduced illumination is being investigated. It can also be employed in classifying personnel according to their visual skills at reduced illumination.

COMMENT

This new device has many interesting features which promise to make it an excellent instrument for mass screening in the Armed Forces. It seems to meet military characteristics from a mechanical and optical point-of-view. It is versatile and can be used in induction centers or in general hospitals. But in addition, it can be easily used for specialized vision testing at training centers where the selection of individuals with special skills is required. Because the target cartridge

can be readily changed, material required by any particular installation can be easily prepared and used as supplementary tests.

SUMMARY

The mechanical and optical characteristics of a new vision screening instrument are described. The machine has been developed to meet the specific needs of the Armed Forces.

Preliminary Comments given by Colonel King

Colonel King made some comments about the Ocular Research Unit for the Army which comes under the Army Surgeon General's Office and then directly under the Research and Development Board. This Unit is located at Walter Reed Army Medical Center. The Unit's chief concern is research subjects of a clinical nature. Most of the basic studies are on contract to various civilian medical centers and universities. The Center's work with toxoplasmosis and with leptospirosis, where they were able to culture for the first time these organisms from the human eye, was familiar to the physicians present, Colonel King said. Also, the Center has other subjects concerned with instrumentation; for instance, an ocular metamagnet which is an electronic instrument as an aid to remove intra-ocular foreign particles of a non-magnetic nature, such as brass, copper, lead, etc. The Center, also, deals with various vision screening devices. Captain Owens prepared a preliminary report on one of these devices. In this report he presented the features of an instrument which was tested and developed at the Center. Colonel King mentioned that several of these instruments were on display in the auditorium and invited the audience to look them over and to feel free to make comments. Colonel King further stated that this machine was not being presented as a validated commercial instrument and that they were not asking for either approval or disapproval, but that they were simply being shown to the group.

Discussion

Dr. Beck noted that there was some distortion in the plastic that supported one of the visual acuity charts which was indicated in terms of irregularities in the surface. Instead of giving a plain reflection it gave a patterned reflection due to a stress pattern. He wondered if this affected visual acuity in any way.

Colonel Sheridan answered by saying that although there is a clearer, harder type of plastic to be had, it was not available in the shops at the Army Medical Center. The plastic that was used came from the Hobby Shops at the Center.

Dr. Mote asked if any studies had been made of the effect on the scores on this from a normal voltage fluctuation without the use of a voltage regulator.

Colonel Sheridan replied that they had not made any, but added that so many people had asked for this addition that they felt it would be a good idea to include it.

Dr. Mote stated that his reason for asking the question was because weight was a problem to be considered. If the normal voltage fluctuation which is something like 4 or 6 volts does not change the brightness so as to bring about any detectable difference in the scores it does not seem necessary to put in this weight-adding unit. Dr. Mote thought that voltage fluctuations are at the level of brightness on the flat portion of the visual acuity curve or perhaps it would not make any difference at all if there were voltage fluctuations there.

Dr. Rowland commented on the high degree of change in luminance with the 25-watt bulb being used in the present Bausch & Lomb model. The higher watt bulb was much less sensitive to voltage change than the 25-watt bulb, and this would very definitely put it outside the range that the Committee adopted. Dr. Rowland felt that it is not safe to have an illumination ratio of more than 1:2, especially since there are other variables such as bulb aging to be considered also. A voltage regulator, if not too expensive, was highly recommended, considering the fact that voltage varies greatly according to locality.

Dr. Mote commented that holding the weight down was more important than the cost involved in using a voltage regulator.

Mr. Middleton said that a 6-volt transformer using ordinary automobile taillight lamps would be a much more practical approach to the problem. The very thin, fragile filaments of the lamps now being used make them unsuitable and difficult to obtain, whereas automobile taillight lamps could be obtained almost anywhere, would last much longer and would be a more uniform product. Mr. Middleton was not sure how much variation there was between the lamps that were being used but he was quite sure that there would be less variation in automobile lamps. The rheostat is not a research apparatus but if variation in illumination is desired one could be used, although for standard conditions a rheostat would not be needed and using one would only add unnecessary weight.

Colonel Sheridan thanked Mr. Middleton for his many helpful suggestions.

Dr. Rowland commented that using a rheostat would give a very undesirable reddish light in the filter although there was a question as to its sensitivity to voltage regulations.

Dr. Locke thought the machine might be further improved if some modification were introduced to aid in the detection of a one-eyed malingerer. It would seem possible for a person to close his right eye by looking into the machine and then when the target was presented for the right eye, he would say that he saw nothing. The examiner would not be able to tell whether his eye was opened or closed. Dr. Locke thought that with so many ortho-raters present in industry the person being examined might have a sufficient knowledge of how these things work to enable him to do this.

Colonel Sheridan said the simplest answer to this problem is using an eye patch and changing the target. He commented that it is difficult to be a really intelligent malingerer, particularly if he were observed closely.

Dr. Harker asked if a 4 or 6 plus correction bulb about 4 to 6" long and 1/2" wide had been tried.

Colonel Sheridan said they wanted to try vapor bulbs but had never done it because they are not easily obtainable. He asked Mr. Middleton's opinion on the use of vapor bulbs.

Mr. Middleton replied and carried on a short conversation with Dr. Harker away from the microphone that could not be understood.

Colonel Sheridan said a lamp without a filament source might have some advantages.

Dr. Rose mentioned that the heavy voltage regulator works on magnetic circulation and that there are other voltage regulating devices like the iron hydrogen lens which would have the added advantage of working on DC current. For world-wide use adaptability of the machine to DC current could be of advantage.

Colonel Sheridan agreed saying that that was a solar voltage regulator which can be custom built, and is strictly AC. The terrific drop in voltage throughout the country is a serious industrial problem and voltage regulation, regardless of how it is done, is important.

Dr. Rowland mentioned two points for Dr. Ogle who was not present. In futher consideration of the malingerer problem, one point was to use a plain, white illuminated surface instead of occluding the eye; that is, it could be done by simply not putting any letters in what the left eye was seeing. The other point raised for Dr. Ogle concerns the phoria tests—the arrow and three dots. Dr. Rowland said it is believed that this is not the proper way to test phoria. Some consideration in a new instrument might be given to lateral phoria.

Colonel Sheridan agreed. He expressed the opinion that these tests rely as much on fusion as they are a test of phoria. There is a tendency to believe that the three dots fusing into the line of dots helps and may falsify to some extent.

Colonel Sheridan remarked that he felt he had learned a lot by the discussion and that he was anxious to get home to try the suggestions.

Dr. Berens commented that this was an excellent example of how the Vision Committee can operate in getting ideas that other groups have.

COLOUR VISION PROBLEMS IN THE RCAF

Wing Commander T. J. Powell, RCAF

The present RCAF methods of testing colour vision for both aircrew and groundcrew are the American Optical Company isochromatic plates and the RCAF lantern. Any subject who fails the plates is tested on the lantern; passing this makes the individual CVD(S); failing - CVD(U). During the war, 1939-40, the Ishihara plates were used with a failure rate of 3.8% of 6000 candidates examined. From 1941 to 1942 these plates and the Eldridge Green or Giles Archer lantern were used and there was a failure rate of 2.8% in 18,500. For the later years of the war the Ishihara or the AO plates plus the RCN or RCAF lantern were used with a failure rate of 4.5% in 100,000. Since a number of aircrew initially examined from 1939 to 1942 are still actively flying it is not surprising, because of the early low failure rate, that a few have been found to be CVD(U) when retested now. This is a minor problem in numbers but a major problem to the individual concerned, who is unfit by our present standard of CVD(S) for trained aircrew and is therefore faced with the prospect of being permanently grounded. An individual who initially passed as CVN and has been tested recently on two supposedly similar RCAF lanterns has completed nearly 4000 hours of war-time and peace-time flying and is now grounded if the regulations are strictly followed. It is estimated that there are 40 to 50 such individuals in the RCAF. The first problem is what should be done with experienced aircrew who are now found to be CVD(U).

A marked difference exists between the results of the tests done by the same experienced operator and it is obvious that the subject has failed both lanterns so there is no real problem. The results of tests done on an experienced pilot with the same two lanterns show that on lantern #15 he passes, but is CVD(U) on lantern #35. The lantern's chromaticity coordinates compare one with the other and compare very well with the coordinates of the Aldis lamp. The only possible variants seem to be as follow:

1. Poor correlation exists between different tests on the same individual, which is unlikely.

2. The neutral gelatin filters are not stable.

3. The lamps have markedly different colour temperatures and this is affecting the results.

The lamps are supposed to be the same, but any screw-type incandescent lamp can be fitted and the Type C, 60-watt, inside-frosted Mazda lamp which is specified is no longer manufactured.

The second problem involved is therefore: should the RCAF lantern be more carefully standardized, after the three factors have been checked, or should a different type of lantern be substituted?

The third problem is closely allied to this and relates to the AO isochromatic plates. We have not a great number of sets of these plates and they are old and occasionally faded. Should the HRR (Hardy-Rand-Ritter) plates be substituted and will they possibly be a satisfactory single test and enable us to dispense with the lantern? This seems unlikely but we have no experience with the use of the HRR plates. Perhaps it would be preferable to retain

our present tests, but we wish to salvage as many CV defectives as possible. It seems improbable that our present standard of CVN for aircrew will be lowered. However, the necessity for CVN may be diminishing with more modern aircraft and perhaps CVD(S) may be acceptable with the greatly increased use of radar and consideration of colours used in the aircraft.

With groundcrew trades the problem is even greater and more complex. About two years ago representatives of all trades in the RCAF were asked by the IAM/CME whether CV was considered essential in their trade. Any obvious anomalies were corrected after consultation, and this is the present scheme; there are many trades allowing CVD(S) and some allowing CVD(U). A difficulty we encounter is that trained and experienced mechanical transport drivers and others are being found CVD(U) on retest and therefore unsuited for their trade. However, this seems unfair as no Province of Canada refuses a driver's license for defective colour vision. While this new present table of standards is considered a transitional one, it must continue in use until more research has been done. This research will consist of making a library of all colours used in the RCAF for coding, and working out their chromaticity coordinates. The electrical trade colour coding is the only one completed at present. The aim of the work is to decide what types of colour vision are required for each trade in which colour codes are used. We appreciate the complexity of the problem and request advice regarding it. We wonder if:

1. The HRR plates might help in allocating our personnel more satisfactorily than at present.

2. A change of colour coding might be possible so that protanopes and/or deuteranopes might be employed in a trade requiring a colour code.

3. Are the present CV limitations of trades satisfactory or do they exclude from these trades individuals who could be safely employed?

In conclusion, the problems are:

1. <u>Aircrew</u>

   a. What can be done for experienced aircrew now found CVD(U)?

   b. Is it likely that the present standard of CV(N) is too high? Note that 2% more aircrew could be taken if CVD(S) is acceptable.

   c. How necessary is normal colour vision in aircrew in modern and future aircraft?

2. <u>Groundcrew</u>

   a. Should the library of colour codes be completed and their chromaticity coordinates plotted? This is a major undertaking.

   b. Is it likely that colour codes might be altered so that protanopes and/or deuteranopes could be employed in trades from which they are now excluded?

   c. Are the present CV limitations of trades satisfactory or do they exclude from these trades individuals who could be safely employed?

3. <u>Methods of Testing</u>

   a. Should the present methods be retained?

   b. If not, what is advised for testing of CV?

Note on the Visual Acuity of Pilots

For many years the RCAF has required a minimum visual acuity of 20/20 20/30 for inexperienced pilots and that experienced pilots be corrective to this standard. It has been suggested that excellent visual acuity is an advantage for jet pilots and that the minimum visual acuity should be 20/20 BE. The problem is whether the standard should be revised, on a sound ophthalmological basis, because some reduction of the available applicants will be inevitable.

Of 4150 new aircrew in the past few years, 3700 have a visual acuity of 20/20 BE and 250 have an acuity of 20/20 20/30. These figures are for all aircrew. For pilots of all age groups, similar figures are: out of 1735, 1500 have a visual acuity of 20/20 BE, 116 are 20/20 20/30, and the remainder have poorer acuity. The reduction of available applicants for aircrew (pilot classification) is therefore not great, and the decision as to future policy of enrollment will rest with higher authority. If, however, a strong case can be made for a recommendation that visual acuity for jet pilots should be 20/20 BE, then it is likely that the standard will be raised.

The antithesis of this problem is the navigator in a two-seater, long-range jet fighter. He can see practically nothing out of the aircraft, unless it is in an extremely banked attitude. He is fully occupied with radar and other instruments, and it seems possible that a visual far point of 3 feet would be adequate. While such poor visual acuity is not advocated, the present standard of 20/60 BE corrective to 20/20 20/30 for inexperienced aircrew, other than pilots, may be too high; a lower visual acuity might be accepted with impunity. Alternatively, a higher correction still achieving this acuity might be allowable.

The problems regarding visual acuity are:

1. Jet Pilots - should the standards be raised from 20/20 20/30, to 20/20 BE?

2. Long-range Jet Navigators - can the present standard of 20/60 BE corrective to 20/20 20/30 be reduced? If not, could those with lower visual acuity be accepted provided they are corrective to these figures?

PANEL PRESENTATIONS OF AIR-TO-AIR VISIBILITY PROBLEMS

A. The Problem of Air-to-Air Visibility

H. Richard Blackwell, Vision Committee Secretariat

This is an unrehearsed procedure which grew out of the informal discussions in the cloakrooms during the last day and a half as to the nature of the meetings we have been holding—the formality of them. And, perhaps, the failure of some of us to make clear the implications of what we are doing. It was felt that if we had a less formal atmosphere for some of the presentations this afternoon that some of these difficulties might be circumvented. The intention of the next part of the program as was set forth on the agenda was really to provide some general discussion of the basic military problems of air-to-air visibility. At one time, as some of you may remember, the agenda carried an item of the discussion of the problem of air-to-air visibility. The agenda that was sent out a short time ago had specific items listed and our discussions of formality suggested that perhaps the first plan was a better idea. So, while we have some specific presentations in mind we do hope to keep this informal and to focus our attention for the first part of the afternoon until the coffee break on the problem of air-to-air visibility. One of the reasons for scheduling this item at this particular meeting was the fact that recently the Secretariat has received from several directions inquiries about this problem denoting the fact that there was considerable contemporary military interest in it. One of the lines of inquiry or expressions of interest came from a group from CONVAIR who it turns out were serving as contractors to Colonel Emerson. And, these people came with the question, "We want to compare the capabilities of the eye to detect military aircraft from aircraft with radar." They wish facts. What are the detection ranges? They had already talked to Professor Duntley and, of course, to Colonel Emerson. They had a good question. In addition to this request for information we became aware of the fact that Colonel Emerson was running some tests of air-to-air visibility through talking with the CONVAIR people. In addition to these two lines of inquiry, two letters have come from the Department of the Navy indicating concern about air-to-air visibility and asking the Vision Committee for opinions as to the feasibility of the two kinds of devices which might be used to increase the capabilities of air-to-air visibility. And, so it seems that this is a good time to sit down and sort of take stock of what is being done and what is known. This really is the intent here this afternoon.

One of the proposals that came from the Navy concerned the idea that visibility at high altitudes is restricted by what is called "space myopia." That is, a myopia that presumably occurs at high altitudes due to the emptiness of space. This is not just a descriptive term but an explanation along with it. Other people have other names for this but this is sort of a tag that carries the concept of space myopia. As you will hear from Mr. McLaughlin that the British have done a lot of work in this area; how people in this country have been worrying and thinking about it; Mr. Koomen of NRL recently put out a report on this subject which we hope Dr. Tousey will comment on if it becomes appropriate later this afternoon. At any rate, we do want to answer the Navy's question, which is, "Does the Vision Committee believe there would be a gain in visibility at high altitudes by any device which might overcome space myopia?" This, of course, implies, is there any such thing as space myopia of any practical importance? The other aspect of the question was, "Would a particular device be useful in this connection and if the Navy proposed that a simple collimated reticle be used, taken aloft and tried out?" They asked the Vision Committee for opinions as to whether this should be done by flying around with this collimated

reticle or whether research should be done or if the whole thing could be answered on the basis of opinion at the present time. We could depart into the visibility of aircraft questions in any one of several directions. Perhaps it might be well to begin by considering the space myopia question, since this is one particular focus of a military problem. Mr. McLaughlin of the Vision Committee Secretariat has assembled some notes as a means of quickly bringing us up-to-date on the research in this field, and paving the way for discussion by various members of the audience. I know that Colonel Emerson has some very definite thoughts on this and he will comment on these at his convenience after Mr. McLaughlin has finished. Mr. McLaughlin's paper is reasonably formal in the sense he has prepared it. We will turn the meeting over to him, feeling free to maintain the informality.

B. Summary of the Evidence Regarding Space Myopia
S. C. McLaughlin, Jr., Vision Committee Secretariat

The term "space myopia" appears to have been chosen by the British Flying Personnel Research Committee. The phenomenon was originally characterized as "day myopia" by RAF Squadron Leader T.C.D. Whiteside and Professor F. W. Campbell in British Flying Research Committee Report #821, entitled, "Accommodation of the Human Eye in an Empty Visual Field." That report described an experimental result indicating that the emmetropic human eye assumes an accommodative myopia in the absence of stimuli to accommodation and convergence. The significance of this finding for military visual problems appears to lie principally in its relevance to the high-altitude air-to-air visual search situation, since air-to-air search at altitude must often be carried out in a realtively homogeneous visual field. At the 31st Meeting of this Committee, November, 1952, Colonel Emerson described three types of difficulties which are frequently encountered in interception above 35,000 feet:

1. Two pilots attempting to rendezvous above a specified landmark have great difficulty in making visual contact with each other, even though they have a good radio communication.

2. If a pilot spots another plane, then looks away a moment, he may lose visual contact completely and be unable to recover it.

3. A plane picked up by radar may come in very close, i.e., close enough to be of greatly supraliminal size and contrast, before it is seen.

It is not my purpose at this time to evaluate further the relative importance of this disturbance of accommodation to the over-all task of visual search at high altitude. Instead, I shall review briefly some of the experimental evidence regarding the existence of what has come to be called "space myopia", and I shall consider some of its implications. It is appropriate to begin with the Whiteside-Campbell report.

Figure 1 shows the apparatus of the Whiteside-Campbell experiment. The observer's head was positioned with a chin-and-forehead rest. He observed the background through a $+4\Delta$ lens. This lens served two purposes: first, it fogged the background so that no accommodative stimulus was visible within 20 degrees of the visual axis; and second, it made possible the simulation of optical infinity with a target at the convenient working distance of 25 cm. The background was evenly illuminated to a brightness of approximately 200 ft-L and subtended 40 degrees of visual angle in each meridian.

The fixation target T consisted of a glass plate on which was a pattern of black dots (inset, Figure 1). Due to their small size (0.1 min.), these dots were visible only when the observer's state of accommodation was such as to place their image very nearly

in the plane of the retina. This fixation target could be moved along the line of sight by means of an optical-bench arrangement.

The eye which was not in line with the test plate had in front of it a +10 Δ lens, which served to blur both background and test plate, thus eliminating convergence cues to accommodation.

The remainder of the apparatus which is shown in the figure provided for the measurement of the state of accommodation of the observing eye by means of photography of the third Purkinje-Sanson images. Since this technique employed a very brief flash of light which occurred only once each twenty seconds, it made possible the measurement of; the accommodative state of the eye without providing a stimulus to accommodation. For each observer, a preliminary series of observations was carried out to establish the functional relationship between the degree of accommodation and distance between the third Purkinje-Sanson images.

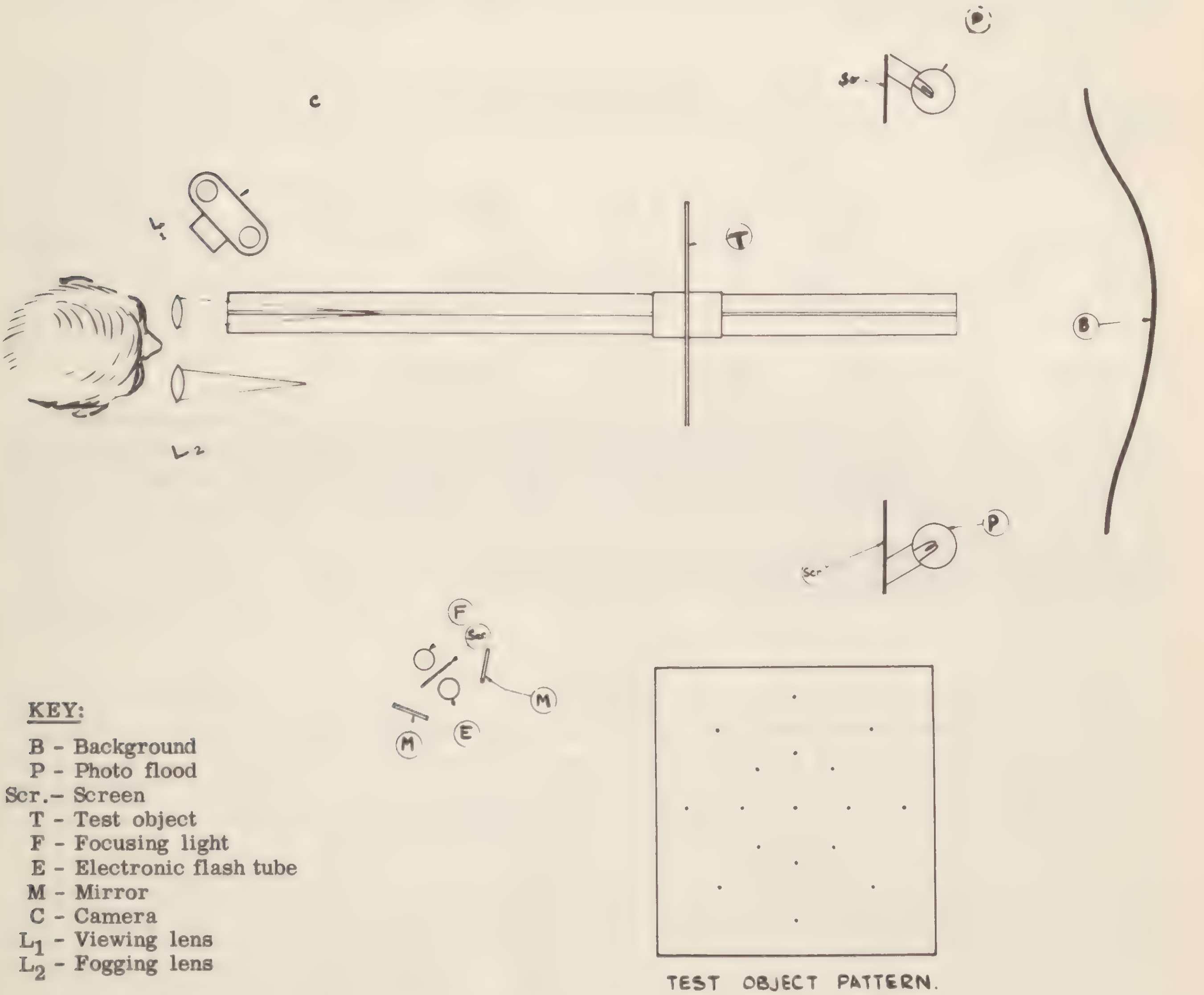

Figure 1. Diagrammatic representation of the apparatus.

Following this preliminary calibration, an experiment was conducted as follows:

The test plate was first placed at a position corresponding to a small degree of positive accommodation, and the observer was instructed to fixate it. The test plate was then moved away in 2-cm steps and at each step a photograph of the Purkinje-Sanson images was taken. The interval between successive exposures was 20 seconds. The procedure was continued until the small dots on the test plate were no longer visible to the observer. The photographs at 20-second intervals were then continued for the remainder of the experimental period.

Figure 2 shows the results for one observer. Since this observer was myopic (degree of myopia not stated, but presumably near +4Δ) the +4Δ lens was not employed in obtaining these results. It will be noted that an increase in refractive power appears to have occurred when the observer viewed the empty field remaining after the disappearance of the test stimulus, and that the degree of positive accommodation varied between 0.1 and 1.5Δ in an apparently random fashion. Table I presents a summary of the results obtained for the other five observers who were employed in this experiment. The mean accommodative power exerted by these five observers was 0.49Δ with a range of .19 to .91Δ.

The authors conclude, "The findings suggest that in the emmetrope, the physiological position of rest of the accommodative mechanism is not, as is generally believed, for infinity, but for a finite distance."

The relevance of this finding to the problem of high-altitude visual search is quite direct, as the statement of Colonel Emerson, quoted above, indicates. At high altitude, accommodative stimuli at optical infinity tend to be lacking, and yet the pilot or crew member must search for targets at a considerable distance. As Dr. Koomen has pointed out in his recently published review of the air-to-air search problem, many factors contribute to the difficulty of the high-altitude visual task, but "space myopia" has the distinction of being one of the few that we may be able to do something about.

This finding of Whiteside and Campbell suggests many lines of further investigation: The role of convergence in the high-altitude search situation; the use of collimated reticles to correct "space myopia"; the possible role of peripheral stimuli in the Whiteside-Campbell experiment; the use of negative corrective lenses to compensate for "space myopia"; considerations of depth of field and pupil size; and others. Before we discuss these, however, it might be well to examine the Whiteside-Campbell finding more carefully, in order to make certain that it stands on solid footing.

Table I

Accommodation in an Empty Visual Field (5 subjects)

	Diopters		
	Min.	Mean	Max.
	.07	.26	.40
	.41	.68	1.32
	.15	.63	1.22
	.26	.48	.88
	.05	.39	.71
Mean	.19	.49	.91

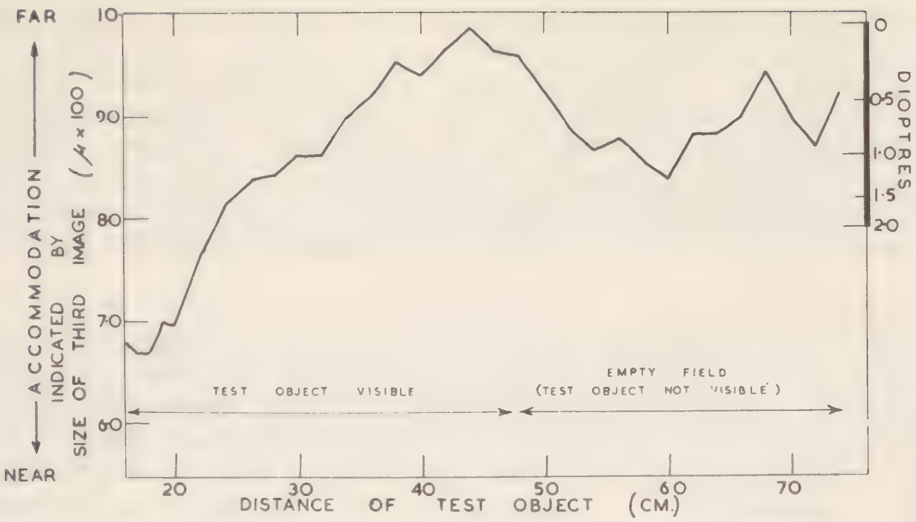

Figure 2. Size of third image when viewing, (a) Test object, (b) Empty field.

This is beyond doubt a difficult experimental problem. Like any experiment in a difficult area, the Whiteside-Campbell experiment has certain characteristics which may eventually be shown to be weaknesses. One of these is the question of the role of peripheral stimuli in this experiment. Such stimuli do not appear to be well described in the Whiteside-Campbell report, and even if they were we would have little to go on in assessing their contribution to the result obtained. However, while criticism on this ground might vitiate the authors' general conclusion regarding the resting accommodative state of the emmetropic eye, the analogy to the high-altitude search situation, where cockpit framing provides peripheral stimuli, appears to be satisfactory.

It may be, also, that the flashes of light at 20-sec. intervals exerted some influence on accommodation in the absence of accommodative stimuli, or that different results would have been obtained with the use of a fixation target which did not constitute an accommodative stimulus. These objections seemed farfetched, however, and it is my opinion that the authors' experimental results support their conclusion, at least with regard to the high-altitude search situation.

We have, moreover, other evidence, from various sources, which tends to support the Whiteside-Campbell conclusion that the accommodative state of the emmetrope in a homogeneous visual field is myopic.

Luckiesh and Moss, in 1940, reported an experiment employing a blurred fixation target which provided no stimulus to accommodation, and a method of measuring accommodation which provided no accommodative stimulus until the completion of the measure. Their 20 observers gave a mean of 0.75 Δ of accommodation in a blank visual field, with a range of 0.38-1.38 Δ. Luckiesh and Moss interpreted this as a functional adaptation to near vision; it appears to be precisely the same phenomenon as that reported by Whiteside and Campbell.

Reese (1939), with no control of convergence, found that the mean accommodative state of his 25 observers was 1 Δ when viewing a blank visual field; and Reese and Fry (1941) obtained essentially the same result in the course of examining the effect of 12 observers of several degrees of "fogging."

Brian O'Brien, in a recent WADC Report, described an experiment in which accommodation was measured in the presence of a homogeneous visual field at several brightness levels. The results showed a mean accommodation of 0.72 Δ at 0.027 ft-L and 0.94 Δ at 0.14 ft-L. These experiments employed a fixation target which provided no stimulus to accommodation.

Henry Knoll, in an experiment with "blob" stimuli which was described before this Committee at its 31st Meeting, presented results showing a relationship between brightness and accommodative myopia similar to that reported more recently by O'Brien. Knoll presented additional evidence indicating that this change was apparently associated with the increase in pupil size at low brightness, and the consequent introduction into the visual optical system of the more myopic peripheral portions of the lens. Such an explanation would not appear to be applicable to the Whiteside-Campbell experimental situation, which was characterized by a complete absence of brightness gradients within the central 40^{o} of the field of view.

In a recent FPRC Report, #850, S/L Whiteside has pointed out another characteristic of visual accommodation which appears to confirm the "space myopia" finding. This is the tendency of the emmetropic eye to over-accommodate for distant stimuli and to under-accommodate for near stimuli: what might be called an "economy of effort" in the act of accommodation. This phenomenon has been reported by a number of investigators, and fits in well with the hypothesis that the resting state of accommodation in an emmetrope is at a condition of positive accommodation. It has been shown, however, (see Ref. 12) that this characteristic of accommodation can be accounted for entirely in terms of the geometric optics of the viewing situation.

It appears reasonable to conclude, at any rate, that the Whiteside-Campbell finding is valid, and we may proceed to the consideration of some of its implications for further research and operational application.

It will be recalled that vergence stimuli were avoided in the Whiteside-Campbell experiment, and this condition obtain also in the high-altitude air-to-air search situation when accommodative stimuli are lacking. It would appear, then, that in the practical situation the resulting heterotropia might contribute more of a decrement to visual search performance at altitude than would the loss of visual acuity associated with a half-diopter of myopia. The experiment reported by Ball (see Ref. 11) indicates that the ACA link holds up in the Ganzfeld viewing situation, and that a "space convergence" accompanies the "space myopia."

Both conditions, "space myopia" and heterotropia, could presumably be connected by the use of an optical device providing a reticle stimulus at optical infinity. A goggle-type arrangement might be designed for this purpose, but such a device would have to meet stringent engineering requirements with regard to weight, compactness, light-gathering power, field of view, etc.

It must also be regarded as unlikely that the addition of another pair of goggles to the pilot's gear will be accepted as operationally practicable. For this reason, it may be well to consider several alternative methods of providing the necessary collimated binocular stimulus.

One such method is to provide a fixed collimated reticle near at hand—say, near the top of the instrument panel. By frequently referring to this instrument, the pilot could repeatedly readjust his accommodation to infinity.

Where the design of the plane permitted it, an accommodative stimulus might be mounted on a wing tip. Such a stimulus should, of course, have sufficient detail to provide a critical stimulus for accurate accommodation.

A third alternative, which was suggested by Dr. McCulloch and Dr. Tousey, is to provide collimating lenses for several of the critical flight instruments, so that the pilot would correct his accommodation for infinity each time he referred to these instruments. This idea appears to have considerable merit.

All three of these alternatives to the use of a goggle system for providing a collimated reticle depend on a considerable time-lag during which the observer viewing a blank visual field gradually assumes an accommodative myopia. The data shown in Figure 2 for a single observer in the Whiteside-Campbell experiment appear to show a lag of as much as one minute, provided that the point of minimum accommodation, rather than the point indicated as "empty field", be taken as the starting point on the curve in Figure 2. Further experimental investigation of this subject is obviously necessary, but the data of Figure 2 indicate that these alternative methods may be feasible.

The use of negative lenses to compensate for this accommodative myopia appears less promising. There is first the difficulty of refracting the observers. In a recent FPRC report, S/L Whiteside describes a technique for this purpose which is similar in principle to that employed by Luckiesh and Moss in the experiment described above. Nevertheless, the apparatus involved and the skill required of the operator appear to offer a considerable barrier to the refraction of large groups of pilots and crew members in this fashion.

A second objection is that we have no evidence that the degree of accommodative myopia in a blank visual field remains constant from day to day or month to month for a given observer. Third, the Whiteside-Campbell findings, as well as those of Luckiesh and Moss and O'Brien, indicate that the degree of accommodation fluctuates over a range of 1Δ or more during a 20-minute period of viewing a blank visual field.

A fourth objection to the use of negative lenses is the consideration that a hypermetropic pilot might encounter difficulty in reading his instruments while wearing a negative correction. And, finally, the use of negative lenses would not correct the condition of heterotropia which may be assumed to exist while viewing a homogeneous visual field.

Another possible means of compensating for "space myopia" is the use of a small artificial pupil, thereby increasing the depth of field of the eye to such an extent that $1\,\Delta$ of accommodation would not blur a stimulus at optical infinity. Since sunglasses are often worn at altitude, the reduction in brightness associated with small pupil size might not be objectionable under some operational conditions. This method, however, like the negative-lens idea, would leave the pilot's heterotropia uncorrected, and has the added disadvantage of restricting the field of view quite severely.

It appears necessary to conclude that neither the negative-correction method nor the artificial-pupil method is likely to be as satisfactory as the use of a collimated-reticle optical system.

FPRC Report, #854, entitled "Vision in an Empty Visual Field-Choice of a Collimated Pattern", by S/L Whiteside, describes an experimental comparison of several reticle patterns with respect to the precision with which each determines the accommodative state of the eye. Of the six reticle patterns evaluated, S/L Whiteside concludes that the most effective is a pattern of dots of smaller diameter than those used in FPRC Report #821, and that the least effective is a simulated horizon. These findings appear to be relevant to the design of a collimated-reticle optical system as well as to the evaluation of the effectiveness of the natural horizon as an accommodative stimulus in the air-to-air search situation.

Many of the interpretations and suggestions which have been included in this review originated with members of this Committee with whom I have discussed the space myopia problem during the course of this meeting. In particular, I wish to acknowledge the contributions of Dr. Elwin Marg, Dr. Louise Sloan, Dr. Kenneth Ogle, Dr. Henry Knoll, Dr. Richard Tousey, and Dr. Clement McCulloch.

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C. Comments Concerning the Difficulties in Air-to-Air Detection at the Higher Altitudes

Lt. Col. George O. Emerson

The importance of target detection in military aviation is well recognized. It is well known that the combat effectiveness of the air weapon system is somewhat proportional to the target detection capability. Consequently, any improvement that can be achieved in target detection will provide a corresponding improvement in the effectiveness of the system.

The Vision Committee has been interested in the problem of detecting aircraft at the higher altitudes. It has been recognized as a problem only of recent years, as we can recall that a few years ago articles appeared, predicting that at high altitudes the visual ranges would be extended on account of the clear atmosphere. Then, when we began to have considerable flight experience above 35,000 feet, we began to receive accounts of the difficulty in rendezvousing. The first popular explanation advanced was that the pilots were trying to rendezvous at a definite locality and at the higher altitudes the difficulty was due to the inaccuracy of their position determination with reference to ground points. However, we have sufficient evidence now that there is no longer a question but there is more difficulty in seeing air targets above 35,000 or 40,000 feet. There are probably several causes for this difficulty. I shall review and give opinions about several of these that have been well summarized in a publication by Koomen,[1] and suggest another cause that hasn't received much attention up to the present.

The first cause to be discussed is glare. Glare usually comes principally from an underlying cloud cover, and not from the sun. The sun at higher altitudes is only about 30 per cent brighter than it is at lower altitudes. However, the clouds are often considerably brighter due to clear intervening atmosphere, occasional ice crystals and concave cloud formations. But more imporant than the increase in cloud brightness is the fact that the brightness is coming from below, for which the shielding is very poor. This glare from below affects the detection problem in several ways. While searching in the upper hemisphere the light scattering in the eye reduces the effective contrast ratio on the retina. On shifting gaze from the lower to the upper hemisphere there is an adaptation required. Thirdly, the unpleasant sensation of glare reduces the time spent in search.

The low contrast ratio of the aircraft against its background appears to be one of the principle causes of detection difficulty. Most of the difficulty occurs when the other aircraft is in the upper hemisphere. Most aircraft have aluminum alloy skins that have a reflectance of 70 to 80 per cent. However, most of this reflectance is specular, so that as far as the illumination from the sun is concerned, it reflects according to the angle of incidence, resulting in an aircraft that appears comparatively dark most of the time. Then in the upper hemisphere there exists a fairly dark aircraft against a dark background.

The third difficulty suggested has been the relative motion, meaning high speed. A few years ago we became concerned about the problem of the visual performance decrement in high speed military aviation. When the difficulty of seeing at high speed is considered, the decrement of visibility according to angular velocity is the thing in mind. However, in practically every problem that we took the trouble to calculate, it was found that the angular velocity was not sufficiently great to cause an appreciable decrement in vision. Then, the angular velocity is of no practical importance in high altitude interception. It is not important because the aircraft maneuvers that would result in high relative angular velocities would require turns to complete the attack, that cannot be accomplished, because the G-force limitations would be exceeded. In almost every case with which we are acquainted the only practical effect of high speed on visibility is in the reduction of search time. However, in air-to-air combat the increase in aircraft speeds does not decrease the search time as much as

[1] Comments on Air-to-Air Visibility at High Altitude by M. J. Koomen, Naval Research Laboratory Memorandum Report 343, 5 August 1954.

would first appear to be the case. Most air-to-air combat maneuvers are approximately tail chases in which case the difference in speeds of the two aircraft is the thing that mostly determines their relative motion. For example, from an exact tail position the relative motion is the same whether the respective speeds are 350 and 400 knots or 750 and 800 knots.

A fourth reason for difficulty is that there is a poor reference for systematic scanning. I think this is responsible only to a limited extent. If the aircraft is flying in a fairly constant attitude the pilot can use the canopy framing and the horizon as a gross reference.

A fifth reason that has been advanced is the narrowness of the foveal field. This is not peculiar to altitude and does not explain the more difficult detectability at high altitudes.

The sixth cause for difficulty is space myopia or empty field myopia. There are three related terms, space myopia, empty field myopia and night myopia. These are related because the same accommodative mechanism is present in all three. Of course the Purkinje shift is not present in the space myopia. For the present the term "empty field myopia" may be preferable because it covers the accommodative element in both of the other cases, and the accommodative element merits the major attention. It is unlikely that spherical aberration accounts for much of the night myopia. In experience in refracting patients with a widely-dilated pupil it is rare that the myopia is increased after dilation by more than one-fourth diopter.

At the Aero Medical Laboratory some work has been done in studying night myopia by means of an infrared retinoscope. Under conditions of low illumination, there has been very little accommodation. However, in complete darkness, the range has been found to be great and variable. We are not prepared to give more definite results at the present time. In the high altitude case, the upper limit of the myopia can be fairly definitely fixed. The pilot is not likely to accommodate for nearer than his instruments and canopy supports, a distance of about 30 inches. Therefore, it is unlikely that he will have a myopia greater than approximately one diopter.

A number of proposals have been made for reducing empty field myopia. If a minus lens is used before the pilot's eye, then he will accommodate to compensate for the lens and the end result will likely be the same as before the lens was used. In other words, if a one-diopter lens is used he will accommodate two diopters. Then there hasn't been much accomplished. The use of a collimated reticle has been suggested. If it is a fixed reticle, it will be effective only when he is searching in the location of the reticle. Then, to be effective, the reticle would have to be projected from his helmet. Those of us who are concerned with the design of aircraft and personal equipment know that we had better avoid such complexity of equipment. We would be handicapping the pilot more than assisting him.

I think there is another possibility in assisting the pilot to reduce myopia. Individuals can be taught to recognize physiological diplopia. They might be taught to recognize diplopia for the canopy supports and thus know that they were converging (diverging) and therefore accommodating for distance. Although it might be debatable as to how much training might be required, it appears that if empty field myopia is a sufficiently important element in the difficulty of air target detection, such training would be a feasible method of reducing the myopia.

Finally, there is another cause of difficulty in detection of aircraft at high altitude that hasn't been discussed very much. The cause is the lack of movement in relation to a background. It is not the single movement of an image on the retina that

so readily attracts attention, but the differential movement, or movement in relation to a background. There are a number of practical flying experiences that demonstrate this behavior. In flying a few thousand feet above terrain, we are able to observe vehicles on the roads. Perhaps we are traveling 150 knots and maintaining our eyes in a fairly constant direction of gaze. Then stationary vehicles and the road will have a fairly constant angular velocity on the retina. These stationary vehicles are not likely to be noticed. However, if these vehicles are moving at only 30 knots, a change of only 20% in the angular velocity on the retina, they readily attract attention. In visual reconnaissance, it is well recognized that a moving object attracts attention much more readily than does a stationary object.

At altitude there is mostly an homogeneous background in the upper hemisphere. Movement against an homogeneous background is approximately the same as no movement, if this movement is inconsiderable in relation to the angular distance of things that might be used as references, such as canopy supports. This lack of an effective background not only reduces detectability but also handicaps the pilot's orientation of the searched aircraft. If he detects another aircraft, glances at his instruments and then looks for the aircraft again, he often fails to find it. He not only doesn't know where it is, he doesn't know in which direction it was going.

It may be predicted that it will be some time before we have reached final conclusions concerning this interesting and important problem of air-to-air detection at the higher altitudes.

D. Commentary on Visibility at High Altitudes

Dr. S. Q. Duntley

There are a few comments which may be pertinent. First, there is a bit of news to be mentioned which was received in my office on Monday regarding a new British report relating to space myopia. Perhaps someone in the audience has seen and read this report, in which case they should be commenting on it rather than I. It is not possible for me to quote the author or the number of the report and I cannot be sure that I am speaking accurately about it. Allegedly, however, the report describes some tests which were made to ascertain fairly realistically, in terms of range, the effect of space myopia or high altitude daylight sightings by pilots. As I understand it, a reflector-type gunsight, such as is commonly found in the cockpits of fighter planes, was used for this test. I am not clear whether this was an outdoor test at ground level, aloft, or something done indoors. I apologize for this. The result, as I recall it, was that if the man looks at the visual field through the reflector sight with the reticle lamp turned off, and establishes the range at which he is able to detect a small, dark object against the bright sky, and then repeats the experiment with the illuminated reticle turned on in order to prevent space myopia by giving him something at infinity on which to accommodate and converge, there is a gain in range by a factor of 2.

The visual detection of aircraft at high altitudes is by no means a new problem to the Vision Committee. Because there are many who are here for the first time today, it might not be amiss to mention a few of the discussions that have gone on in the past. One classic report was made at the Norfolk meeting of the Vision Committee by Drs. Lamar and Kimball, formerly of the Operations Evaluation Group in the Navy. This should be referred to in our Minutes. Later, Dr. Lamar extended the work in a paper given at one of our Washington meetings. The visual search problem was treated quantitatively in terms of its detection probability using the results obtained by the Tiffany Foundation for determining maximum ranges and the results obtained by Craik in England for the considerations of the probability of seeing by means of more peripheral parts of the visual field. Recently, the Bureau of Aeronautics, U.S. Navy, has published a study using the basic concepts and data of Lamar and Kimball. I will not discuss this classified report here, but anyone who is concerned with this problem should obtain that document through proper channels. There have been other reports on air-to-air visual search by the British, by ourselves, and by the Canadians. There is quite a lot of literature, and several references can be cited in our own Minutes on this problem.

My laboratory is deeply concerned with air-to-air visibility. We are collecting fundamental data on the inherent contrast of aircraft aloft, and on the optical properties of the atmosphere at all altitudes. I have reported on this work to the Vision Committee in the past, and there is nothing that I wish to add just now, except to say that we are working very hard on it. Perhaps by the next meeting we may have some very substantial data to tell you about.

I wish to agree with Colonel Emerson's remarks about the low contrast aspects of aircraft aloft and to amplify them somewhat. They are mirror-like objects which form virtual images of the sky around them inside their own confines. In many cases the air-to-air contact is horizontal, or nearly so, and the virtual image of the horizon which is formed by many parts of the curved surface of the aircraft appears as an area of low contrast. The upper part of the aircraft tends to appear dark because it forms a virtual image of the dark upper sky. This is offset, however, by sunlight diffusely reflected from the metal surface of the aircraft. This tends to balance the lack of luminance in the image of the upper sky, so that these two effects tend to compensate and result thereby in low contrast. At high altitudes the upwelling light is usually quite large in magnitude and tends to lower the contrast of the under portions of the aircraft much more than might be expected on the basis

of low altitude observation. From every direction mechanisms are at work which tend to lower the contrast of aircraft at high altitude.

Glare has been mentioned as troublesome to pilots at high altitude. One should not forget that the sky is dark and the upper sky is much darker than at low altitude. This tends to increase the effectiveness of the sun as a glare source.

The presence of an undercast causes the upper portion of the retina to be illuminated to a greater extent than the lower portion of the retina. This sort of visual field is found outdoors after a snow storm when dark-blue sky appears and the brighter part of the field is beneath and the darker part of the field is above. Everyone knows that this unusual situation is uncomfortable. Comfort can be increased by blocking off the light from the snow. This is the same effect, I think, that bothers pilots aloft, particularly above an undercast.

In closing, I would like to suggest a means to combat empty field myopia. One type of collimated sight, developed by the Polaroid Corporation during the war, is commonly called an "optical ring sight." It should be feasible to mount such a sight in front of the eyes as an attachment to the visor of a helmet. It would project a pattern at infinity which would enable the pilot to accommodate and converge at infinity. This might wipe out empty field myopia. We have with us today the man who was responsible for guiding the development of the ring sight during the War. Dr. S. S. Ballard, who then was Commander Ballard in the Bureau of Ordnance, had charge of the contracts under which this device was developed by the Polaroid Corporation. I hope Dr. Ballard is willing to comment on the ring sight and its possible applicability in correcting empty field myopia.

Discussion

Dr. Ballard agreed that one of these ring sights could be easily pulled down in front of one eye. He did not think it should be in front of both eyes because two ring sights showing reticle images might give some difficulty. He said the Polaroid ring sight is a good collimated sight except for the fact that it has a rather low transmission, 25% or 30% at the most, and there is a rather diffuse reticle pattern, that is, these rings are not too sharp; they are about as sharp as Newton's rings. He further stated there is another sight known as the Cystoscope sight which was developed at least partially as a result of the enthusiasm of the Vision Committee during the War. The collimation of this sight is done by a half-silvered Mangin mirror and it has the following advantages over the Polaroid sight: any desired reticle pattern can be put on it; for example, one circle that would not be very noticeable could be placed out near the periphery. This ring could be made quite sharp, in contradistinction to the pattern that the Polaroid sight gives; the transmission might be somewhat higher, and it would be a lighter weight device. The weight is important for something that hangs on a pair of spectacles or goggles. Dr. Ballard did not know whether The American Cystoscope Makers still manufacture this device, but he said it was a fairly simple thing to make.

Dr. Blackwell suggested discussing all other questions first and coming back to the night myopia problem later.

Dr. Baker mentioned several other pertinent problems. For instance, what effect does diffusion of jet gases—atmospheric boil—have on vision at altitudes; what does tremor do to visibility at altitudes? Dr. Baker remarked that under certain conditions the low altitude of the sun is such that in one position an aircraft will present negative contrast as the target to the observer, whereas, swinging

around another hundred and eighty degrees presents negative contrast to the observer. Somewhere in this hundred and eighty degrees this target must have gone through zero contrast. This being the case it must have been invisible. Dr. Baker suggested that a number of reports of visibility are a result of this fact.

Dr. Hartline commented that there is another element to be considered with regard to high-altitude observation, namely, the fact that it is really possible to see some of the brighter stars in full daylight if one knows where to look. If an astronomical telescope is directed at a bright star by setting it at the proper altitude and azimuth, it is then possible to sight along the finder sights of the telescope and see the star. But, if one looks away for a moment, it will again be impossible to see the star, without using the telescope sights. Presumably, this is due to the very high acuity of the fovea and the fact that acuity falls off so rapidly away from the fovea so that one is really blind for very small objects outside the fovea.

Dr. Blackwell recalled that at the meeting in San Diego data on the change in contrast requirements as a function of the degree of the axis of viewing was presented, showing that at high brightness levels as one proceeds from the axis to 12^{o} off the axis there is a change of more than 50:1 in the contrast required. Over a matter of about 2^{o} this is a ratio of 2:1 or 3:1. More recently, on the basis of Dr. Hartline's type of observation made both indoors and outdoors many years ago, Dr. Blackwell said they went down in the neighborhood of extremely small separations. It was concluded that if one knew precisely where to look and found it, it was clearly visible but if it moved off the axis infinitesimally far it was lost. This presented the fact that by going off no more than 10 minutes of arc for white light at high brightness level the threshold changed almost 2:1. The change during the first few minutes was rapid.

Dr. Blackwell commented on the relevance to this discussion of a previous remark of Mr. Tanner's where he mentioned the earlier work of the Operations Evaluation Group with regard to their attempt to compute detection lobes; in these data the calculations were based upon information such as the ones described here, obtained an experiment in which the observers knew where the target was to come but were instructed to look away from it. He recalled that Mr. Tanner's experiment concerned cases where the observer not only looked away from it but did not know exactly where to expect it to come. Put in this framework, Mr. Tanner's results can be shown to indicate an additional factor. The numerical value for the "threshold" for 5^{o} to positions of the target which can occur in these two positions being off 2^{o} in each direction from the fixation point is approximately 30% to 40% or a ratio of 2:1. It had been thought that somehow this was a factor that had never been taken into account in the detection lobe-type of calculation. And, these experiments of Mr. Tanner's were the first Dr. Blackwell knew about in which this was assessed. To summarize, this means that knowing where to look for or finding and keeping the target is a very different matter from trying to find it, both because of looking in the wrong direction, and also, because of the fact that one does not know where to expect the target to appear, additionally raises the threshold. LCDR Knight, U.S. Navy, sent in a statement to the effect that one of the critical features of high altitude visibility was the lack of relative motion with respect to reference, and proposed that a reticle be put out into space which would be vibrated and which would provide relative motion compared to a target. This idea was identical with that of Colonel Emerson. The fact that, not only is there low contrast at high altitudes, but also there are often negative contrasts, is a

reminder of the observation that the contrasts not only go to minus one in the direction of dark targets, but, can go to infinity in the direction of bright targets. Since it is possible to see bright targets much farther than dark ones, and this means that if the illumination conditions at high altitudes provide dark targets as well as no contrast then loss can be expected for that reason alone, because the contrast will not be big enough to be the equivalent of the contrast at low altitude. Finally, General Maxwell, formerly a member of the Vision Committee and now with the Alaskan Air Force, who has been concerned about the problem of glare at altitudes, did some work in Alaska last summer with Dr. H. Kuhn. Dr. Blackwell mentioned that General Maxwell commended Dr. Kuhn for solving the problem of glare at altitudes. Dr. Kuhn reached her solution by cutting off the bottom half of an ordinary pair of sunglasses, so that by looking out into the space world one had a sunglass of high density to reduce the over-all brightness of everything in the field, and yet, when looking down at the instrument dials there was no loss of light. Dr. Blackwell said that Dr. Kuhn had sent him a pair of these glasses.

Dr. Knoll made a few comments on the problem of empty space myopia. He agreed with Colonel Emerson that this really should be referred to as empty field myopia since myopia is not associated with space per se, but rather is the absence of optical stimuli when one is flying in space. Dr. Knoll did not agree with Colonel Emerson, however, in that this phenomenon could be classed under the same title as nocturnal myopia, since different factors contribute to the two myopian situations. In the case of nocturnal myopia, Dr. Knoll said it was necessary to definitely accept the contribution of the chromatic and spherical aberration effect, the dilated pupil plus some posturing of the lens. Then, one might be referred to as scotopic empty field myopia and another as photopic empty field myopia. He wondered also whether this is not the old myopia which was known as "instrument myopia." There was some doubt as to whether anyone had yet really measured empty field myopia. Whiteside's experiment, previously described, very definitely involved the situation of looking into or looking through two lenses. The subject was not being fooled by this at all; he knew where he was, what he was looking into, and what he was looking at. Dr. Knoll was concerned about how the problem of empty field myopia was going to be attacked. As soon as one tried to measure the refractive state of an empty field it is no longer empty. The possibility of getting a large integrating sphere and placing a subject within that sphere had been thought of, but the problem of putting an instrument in the sphere and still maintaining it as empty has not yet been solved.

Dr. Marg suggested that perhaps this phenomenon could be called visual acuity myopia. His suggestion was based on some recent work that was done for a Master's thesis at the University of California by Gordon Heath, in which Mr. Heath varied visual acuity by putting thin, ground-glass plates before targets and as the acuity decreased from 20/15 to a mere shadow, gradually he refracted up to about a diopter and a quarter of what would be called today "space myopia." Also, if -6 lens is used before the eyes in accommodative stimulus he found that as he went from 20/15 to 20/8/100ths and a mere shadow, the accommodative response which was near -6 to start with, terminated at about a diopter and a quarter. This is the equivalent of what used to be called "nocturnal presbyopia." So, perhaps poor visual acuity rather than emptiness is the important thing. Dr. Marg made another suggestion concerning reticles or the use of sights. In certain positions the pilot, and co-pilot, who does not use a sight, might be rather restricted when he wants to look around as much as possible in the visual sphere. It seems that the next step might be trying minus lenses to

correct night myopia. The project to use an infrared skiascope was initiated. The object being to measure individual changes in the refractive state under these conditions and in these individuals actually to try minus lenses, taking into account their ACA ratios and vergences as far as comfort goes. Off hand, on a purely curbstone basis, it would seem that with adequate vergences of a low ACA ratio and with an ample amplitude of accommodation that minus lenses might be the simplest solution where reticles cannot be used.

Colonel Emerson mentioned that some actual flight testing is going to be done to determine ranges in various illumination conditions, and actual detection ranges. The expectations are that this will provide more effective air weapons and assist in scanning patterns. It would be desirable to scan the number of fixations, and it would help in advising the air weapon system designer whether to supplement the direct visual field with electronic means or other devices.

Dr. Blackwell commented that both he and Dr. Duntley hoped to cooperate in the tests which Colonel Emerson was running, to provide physical documentation of conditions under which the tests are made. It is hoped that the University of Michigan B-26 aircraft will be available with a calibrated aerial camera to take photometric photographs of these targets against the background so that some facts can be obtained as to contrast and background brilliance to allow us to understand the results Colonel Emerson gets.

W/Cdr Powell mentioned that he had been one of Whiteside's experimental subjects when he was at Farnborough. There was one question in the first paper as to whether there was any peripheral visual stimulation or not. As nearly as he could remember in looking down a dark tunnel of about 15° there seemed to be no peripheral stimulation at all. The other one—the last comment—was that nobody was fooled because the subject was looking through two lens systems. W/Cdr Powell further stated that he couldn't see the target. He was led into a darkened room and apparently was peering out into space. One gets the impression of looking at a distant object and it was a surprise afterward upon seeing the apparatus to learn that you were not looking out at all.

Dr. Fitts commented that several speakers had emphasized that one of the problems here was looking through the wind screen. One might be looking through some very good cues for accommodation, and suggested that this should be investigated. Any experiments done in looking without having some cues in the immediate program might be suspect in this regard. Scratches, grease, or things of this sort on the canopy might be very good cues for accommodation. Dr. Fitts also mentioned the fact that midair collisions under good visibility are becoming an increasingly important problem in civil aviation. There are two things going on that might not be known generally by the Vision Committee members. The Air Transport Association recently invited airline pilots to make anonymous reports of near misses. It was Dr. Fitts' understanding that these have been coming in at a very high rate. This might be useful information. Also, the Civil Aeronautics Association Technical Development Evaluation Center at Indianapolis has been running an excellently designed airborne study of collisions, or rather the probability of detecting collisions as a function of the angle at which the collision is occurring, and have been photographing eye movements of pilots who are flying the airplane and searching. This may give some very interesting data, also.

THE ASSESSMENT OF VISUAL DISTORTION THROUGH AIRCRAFT TRANSPARENCIES

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For some time to come a significantly high percentage of the information concerning the surroundings of an aircraft during flight will be secured by visual inspection. Electronic instrumentation to furnish the pilot with representations of what he needs to know concerning the nearby terrain and air has not yet reached the stage where direct visual inspection can be entirely eliminated. When permitted by weather and ambient light, vision is used for this purpose.

In an aircraft, visual inspection is usually through glass or plastic transparencies. Such observations are not equivalent to those obtained by direct vision. Vision through a transparency equivalent to direct vision may be obtained only if all the following conditions exist:

(a) The transparency is spherical in shape.
(b) The radii of the inner and outer surfaces are precisely maintained and measured from the same point.
(c) The observer's eyes are precisely in the center of the sphere.
(d) The material of the transparency is free of any filtering effect, bubbles, and surface imperfections, foreign matter or striations.

The perfection just outlined is, of course, not a practical necessity. There is no doubt that in the ordinary course of flying, small visual inaccuracies can be tolerated. It seems reasonable, on the other hand, to expect that when they are larger, erroneous perceptions of the visual environment can result in annoyance, fatigue and even piloting errors, particularly after long periods.

Aviation personnel object to obvious optical imperfections in aircraft transparencies such as bull's-eyes, crazing and scratching of the surface, and imbedded foreign material. Furthermore, they object to "distortions" which in the more serious forms interfere with detecting targets visually and cause a reduction in the ability to make proper estimation of size, form and distance of sighted objects. One recognizable visual form of distortion is the appearance of undulations in the contour lines of sighted objects. Although object recognition is not seriously interfered with, the perceptual error manifested by such waviness may have important consequences. Fatigue could result, for example, from a long-continued effort to avoid viewing through the distorting portion of a transparency. Such effects are difficult to evaluate objectively, and even subjective reports give little basis for estimating their extent.

While it is recognized that distortion is to be avoided in transparencies, considerable difficulty is experienced in detecting and evaluating it. In brief, tests of distortion which have been proposed and used in the past have usually been of one of two extremes, neither of which is totally satisfactory. One type of test requires arduous measurements of the angular changes of light paths caused by small elements of the total transparency. Such tests of deviation alone are not directly indicative of the extent of visual distortion since it is the

variation of deviation which causes the visual distortion of objects rather than magnitude of deviations at individual test points.

The other general type of test method being used requires a subjective evaluation by an inspector either by viewing through the transparency or by examining the pattern of light projected onto a screen through the transparency. With such tests, standards are too variable and their relationship to the visual requirements of the ultimate user, the aviator, are uncertain.

An important consideration in any inspection procedure is the fact that aircraft transparencies, especially curved glass, are expensive. Indiscriminate or arbitrary rejections would not be desirable. Overly rigid standards which do not take into account the existing state of the fabrication art will result in an unnecessarily high rejection rate although they may assure high quality.

In recognition of the visual and logistic problems existing because of distortion-producing transparencies, the Bureau of Aeronautics requested that a study be made of the possibility of establishing an improved distortion testing technique. It was considered that the following features should be incorporated in an inspection test:

1. A procedure simple enough to be used in a production-inspection activity.
2. An objective method of evaluation.
3. Criteria of acceptability based upon the visual effects experienced in actual use in the aircraft.
4. A permanent record of the test.

Major attention in this study was to be paid to the question of distortion evaluation in curved windshields. Curved rather than flat windshields have found wide acceptability mainly because of aerodynamic considerations. The use of flat windshields would, of course, reduce the distortion problem, especially if the lines of sight were close to normal through them. Flat panes placed so that the lines of sight have angles of incidence other than normal produce their own visual distortion problems which can manifest themselves in several ways, e.g., impairment of depth perception.

Hartline[1] has made a thorough study of the incidence and cause of distortion in aircraft transparencies. He concluded that the amount of deviation of light rays through a transparency can be expressed as a function of: (a) the amount of wedge in the pane, (b) the amount of curvature of the pane, and (c) the angle of incidence of the line of sight. Deviation causes points in the visual scene to appear spatially displaced, and when deviation is variable through the section of windshield through which a scene is examined, the scene is said to be distorted.

Varying deviation in curved or in flat wedge windshields is usually accompanied by varying linear displacement. The net visual effect is the result of the addition or subtraction of the two, as the case may be. Varying linear displacement occurs even when viewing through a perfect, flat pane because the eye position is fixed and the lines of sight vary as to angle and, therefore, as to amount of displacement. This enlargement or contraction in the apparent size of sighted objects can be called distortion if the definition is broadened to include the cases showing only varying displacements. However, in common usage, distortion is considered to exist only where varying deviations produce the visual effects of waviness and irregularities, rather than the less obvious size changes caused by linear displacements alone. Hartline[1] has pointed out that, depending upon the sighting angle, some linear displacements can cancel deviations and, visually speaking, no distortion is apparent. It is possible to introduce such compensations deliberately by controlling the thickness in the curved portions of transparencies.

In summarizing, it is apparent that the distortion which confronts a pilot in sitting in an aircraft cockpit is the final result of the nature of the windshield itself and the manner of sighting through it. The influence of the several factors in producing the final visual result are difficult to assess in isolation. It follows that perhaps the only suitable practical test of distortion is one which empirically evaluates the final visual effect. Such a method would rate windshields only with regard to the manner in which the observer's vision is distorted. The contribution of each factor to the final distortion would not be evaluated, since such a breakdown is usually not necessary in acceptability testing.

The studies conducted in connection with this problem at our laboratory were divided into three phases:

1. Development of an inspection method[3]
2. Validation of the method[4]
3. Drafting of specification requirements[5]

Subjective Rating of Windshields

The first task was to grade windshields with respect to the visual impediment introduced by their optical qualities. Considerable effort was expended in reviewing the pertinent literature and in conducting tests which required subjects to perform some basic visual tasks while sighting through some apparently distorted windshields. Visual acuity, form recognition and depth perception tests yielded no data which would satisfactorily grade the windshields. One important difficulty arises from the necessity to control strictly the portions of the windshields through which the subject is sighting. The readiness of an observer to change his line of sight to avoid a distorted area means that a measure of occurrence of this distortion would be revealed only with great difficulty by this type of test.

As a result, it was decided to use other available methods which could be expected to provide grading of the windshields with respect to the visual manifestations of distortion. These methods consisted of preference and rating surveys, using experienced pilots as subjects. It was hoped by these methods to provide statistically valid information which would take account of the importance of the various portions of the windshields in the pilot's visual observations while performing his flying duties and of the relative visual difficulty introduced by varying amounts and distributions of distortion. In this way, the pilot's own estimation of his normal manner of using windshields when flying would govern the results of this survey.

An adequate subjective scaling of windshields is possible only if a number of them are available which exhibit distortion of sufficient magnitude to be detectable to the subjects. However, they should not distort the visual test scenes so grossly that the windshields cannot be logically differentiated as to amount of distortion.

After preliminary tests to select a series of F6F side windshield panels, a paired comparison test was conducted at the top of a seven story building overlooking a runway of Mustin Field. The subjects, experienced pilots, were seated in a comfortable chair from which they could see the full length of the runway through a large open window. A sliding frame was placed in front of the subject so that either of the two paired windshields could be placed quickly before him. The frame was placed in such a manner that the runway was visible through only one windshield at a time. From the data the fifteen windshields were scaled in terms of the subjects' opinionns of the relative amount of objectionable visual distortion.

Development of an Inspection Test

1. Single Aperture Photography

The selection of a good inspection method requires that in addition to predicting pilot preference, the method must be one which is suitable for use in a production situation. Further, it would be desirable to have a permanent record for each windshield. A suitable test should be not only simple but also brief and amenable to use by relatively untrained personnel.

Many suggestions of a suitable technique were examined for their applicability and for inclusion of desirable features. Kay[2] has analyzed most of them and concludes that many are unsuitable because they determine deviation, rather than variation of deviation. Others are unsuitable because they allow too much leeway to inspection personnel in making what are essentially subjective determinations.

Photographic methods appear to meet all the requirements since a photograph with the required controls may be taken quickly by inspection personnel. A photograph provides a permanent record which may be examined at a time and place that will not disrupt the manufacturing process.

Essentially, single-aperture photographic methods consist of photographing a grid of lines through the transparency being tested. The grid provides a continuum of points to be observed for differential deviation. Differences in deviation along the surface of the transparency result in crooked, wavy or angled lines in the grid photographs.

Films taken in this way were examined in a Recordak (Library Film Reader, Model C) and were analyzed to check upon three possibilities for a quantitative index of objectionable distortion:

(a) large localized deviation changes,
(b) general waviness of lines over large areas, and
(c) change of line direction followed by a return to the original direction within a selected distance.

Examinations based upon the first two possibilities showed little correspondence to the order of preferences indicated by the paired comparison study. An analysis was made based upon the third possible index with ten grid squares used as the selected distance within which instances of change and reversal of line direction were counted. This type of double direction change can be called, simply, reversal. It appeared that reversal in the vertical lines in all the windshields was proportional to the total of horizontal and vertical line reversals. A count was made of reversals of vertical lines; it was found that the windshields could be arranged according to this count to agree with the subjective ratings.

An alternate method of scoring was found to consist of counting only the number of large squares (each 10x10 grid squares) containing any reversed lines. It was found that the better windshields had between zero and four large squares containing reversed lines; for the windshields subjectively rated poorer much larger numbers of the pattern of large squares were found to show reversed lines.

From this analysis it was recognized that an important characteristic of windshields rated poor with respect to visually-evaluated distortion is the extent of the distribution of distorted areas as revealed by grid line reversals. Comments of the subjects during the preference rating tests and examination of their choices also seemed to indicate that they object more to the extent over which there is a relatively mild distortion than they do to a more severe distortion which is limited in area.

A review of the inspection of windshields up to this point indicated the practicability of a rating technique with which to detect in each of a number of defined subareas of a

photograph only the presence or absence of a defined distortion level, and with which to count the number of subareas in which it occurred. A more detailed quantitative determination of distortion might be an unnecessary refinement for an inspection test for visual acceptability. For example, counting for the entire windshield the total number of closely-spaced points where excessive deviation variation occurs might be too detailed a method.

2. Double Aperture Photography

Photographic methods that used double-aperture (or lens) photography of a line grid appeared to represent a next logical approach to a test which would provide an easily evaluated estimation of the degree to which a panel is distorted. The double-aperture method adopted in the present study involved photographing a grid with a 35 mm camera over which a lens cap with two small holes had been placed. The result was a negative on which distorted areas of the transparency were indicated by separate recording of the two images of the affected portion of the grid line. Thus, a gradient of deviation in the panel was indicated by grid lines which appeared to split. The absence of distortion was indicated by unsplit grid lines which appeared when the two images coincided.

In addition to being essentially a distortion-no distortion test, this method has several other advantages. It is simple in that it requires no photographic work beyond taking the pictures and developing the film and in that the presence or absence of distortion is indicated by a type of line (i.e., a split line) rather than by a shape of line (i.e., angular direction). Thus the effects of dimensional artifacts arising in the development process and in the enlarging process may be minimized. The film negatives taken this way showed some split lines for all those panels to which the pilots indicated some degree of objection concerning distortion. Thus, it was possible to compare the number of split lines to the subjective preferences.

The 35 mm negatives were examined in a Recordak which enlarged the 35 mm negative to an 18"x18" projected image. This examination gave results which indicated that the count of split lines related closely to the position of the panels in the preference scale. Several counting procedures were utilized, and various ratings were made from the negatives. The one which appeared most suitable was selected for further investigation.

The method deemed most appropriate involved preparing a transparent templet on which lines were drawn which divided the film image on the Recordak screen into sections, each of which contained one hundred of the grid squares. Each templet section was examined and scored a plus if a line or portion of a line was split and a minus if there were no split lines in the area. The number of plus templet sections then became the numerical distortion rating of the windshield.

Test Validation

It was necessary to cross-validate the test, that is, to determine the extent of agreement for a different set of windshields, with different judges using the inspection test and different pilots determining the criterion, where these judges and pilots have no information about the experiment other than that given to them explicitly. This cross-validation was the purpose of the validation experiment.

The sample of windshields was selected in three ways. First, the sample was taken from about seventy-five windshields that had been produced by being subjected to varying magnitudes and directions of stress during fabrication. In the judgment of the production facility, this produced windshields that represented the kinds and range of distortion that could occur in normal production methods. This deliberate production of the sample was necessary because random selection of windshields from the production line at certain time

or output intervals would require a prohibitively long time due to the infrequent occurrence of quality changes in production.

Second, windshields were selected from this group so that they showed no apparent scratches, blemishes, discolorations, or "bull's-eyes." This is part of the usual inspection procedure at the production facility.

Third, from the remainder, twenty-five windshields were selected by the project personnel in an attempt to include at least one each of the possible different scores on the inspection test.

1. Inspection Test Scaling for Windshield Distortion

Photographs were made of each of the twenty-five windshields by the double aperture technique. These were judged by a group of seven enlisted men, who were administered the test individually. The order of presenting the twenty-five photographs was randomized individually for each judge. The results of this administration of the inspection test were scores and averages of scores for the twenty-five windshields and seven judges.

The results indicated a statistically significant agreement in relative scoring of the windshields but disagreement as to absolute scores. It is suggested that better selection and training of the judges would reduce the disagreement.

2. Criterion Scaling for Windshield Distortion

As a criterion for the inspection test, the same set of windshields was ordered, according to a judgment of suitability for use in aircraft, by a modified method of paired comparisons. The modification was to reduce the number of pairs presented to any subject. Rather than presenting the three hundred pairs that would be required if each windshield were to appear with each other windshield, one hundred pairs, in which each windshield appeared eight times, were presented.

The subjects were eleven Navy pilots. The test determined that there is relative agreement among pilots in scoring windshields.

3. Validation of Inspection Test Scale against Criterion Scale

Having shown that there is reason to believe that the individual inspection test scores and the combined criterion scores are adequately reliable, it was then possible to estimate the agreement between them.

The combined correlation coefficient is -.782 and is significantly different from no correlation at the .01 level. Therefore, the cross-validation indicates acceptable agreement of inspection test and criterion.

It was concluded as a result of these validation tests that:

a. On the inspection test, judges agree relatively but not absolutely in scoring this set of windshields.

b. On the criterion scale, pilots agree relatively in scoring windshields.

c. The inspection test, even when used by one judge only, discriminates reliably among windshields in this set.

d. The averaged criterion scores discriminate reliably among these windshields.

e. There is significant agreement, for windshields selected as were these, between individual inspection test scores and averaged criterion scores. Therefore, to the extent that the selection procedure does not bias the sample tested in this experiment, the inspection test is adequately valid.

Development of a Specification Method

The maximum deviation gradient in transparencies may be in any direction. For any transparency the direction of the maximum deviation gradient is influenced by the design and the fabrication technique. Therefore, photographic inspection in at least two directions perpendicular to each other will be required to indicate the components of the maximum gradient. The maximum gradient, if in other than the two inspection directions, will not be fully indicated. However, the evaluation technique developed provides a reliable indicator of visually objectionable distortion even though the photographic representation does not indicate precisely the maximum deviation gradient.

The extent to which distortion is visually objectionable can be evaluated in terms of two general qualities:

1. the magnitude of distortion in any limited transparency area; and

2. the extent of the area over which the distortion is exhibited.

For determining the distribution of "Distorted Subareas", each numbered subarea is examined to see if any split lines occur. Each subarea exhibiting line splits in the photographs made with either horizontal or vertical aperture alignments or both shall be counted as one "distorted" subarea. A total count of the number of subareas in which one or more split lines occur is made. This determination is referred to as the "Distribution" determination.

The total number of line splits (combining the vertically and horizontally aligned aperture photographs) in the subarea showing the greatest number of line splits is determined. In order to determine which subarea has the maximum number of line splits, it may be necessary to make a count in those several subareas which in a general inspection appear to have the largest number. This determination is referred to as the "Maximum-splits" determination.

Because of the design of specific transparencies, certain sections may be highly prone to exhibit some degree of distortion. If sighting through such sections is not frequent and if the operational employment of these sections is not critical, these sections may be classified as "distortion inspection-free."

Those sections of a transparency which are important operationally or are used frequently require quality control with respect to distortion. In those transparency sections which require such quality control but where design, fabrication, or installation characteristics result in proneness to visual distortion, a less stringent requirement than would otherwise be specified may be applied.

After a number of transparencies have been inspected by photographing with both horizontally and vertically aligned apertures, it may become apparent that either of the two aperture alignments provides a consistent and proportional representation of the total distortion. In other cases, it may be found that one or the other of the two photographs always provides the overwhelmingly major portion of the line splits. If either of these

conditions exists, it may be decided to simplify the inspection procedure so as to require only one photograph.

Transparencies may be rejectionable because of exceeding the "Distribution" or the "Maximum-splits" limits. These requirements, therefore, can be specified for procurement as follow:

1. The maximum allowable number of distorted subareas (Distribution).

2. The maximum allowable number of splits in an individual subarea (Maximum-splits). It may be necessary in specifying this requirement to indicate different allowable maximums for specifically numbered subareas. Such differentiation would allow for inspection standards based on operational need and the achievable distortion freedom permitted by the design factors existing in each subarea.

The limits for these requirements are to be prescribed by the procuring agency. The considerations which will govern such prescription are:

1. The quality of the product achievable by current fabrication techniques;

2. The quality of product permitted by the required transparency configuration;

3. Cost of the final product as related to the inspection rejection rate; and

4. Service reports of difficulties or complaints in the use of a transparency inspected in accordance with an existing set of requirements.

Initially, a set of procurement requirements for individual transparency designs will probably be established on the basis of considerations 1, 2, and 3. It is suggested that a practical method for accomplishing this would be to require pre-production sampling. For each transparency design for which procurement from any one vendor is being initiated, a small number (four to six) of the initial production would be submitted for laboratory test. This sample should be certified by the vendor as being of standard production quality for this design and as meeting all other specification and design requirements. The laboratory test contemplated would include application of the distortion test described herein. If, for each of these samples, the number of distorted subareas (Distribution) is less than 25% of the total number of subareas, then the interim requirement shall be set at a maximum of 25% of the total (extended to the next higher whole number). If, for each of these samples, the maximum number of splits in any individual subarea (Maximum-splits) is less than 50% of the number of subarea lines in the determination (horizontal, vertical or the combination), a maximum of 50% of the lines used extended to the next higher whole number shall be set as the interim requirement. If, on the other hand, for any of these samples, 25% or more of the total subareas are distorted and/or any individual subarea contains splits equal to or exceeding 50% of the number of lines used in the determination in the subarea, an evaluation study of the transparency design will be made to establish the requirements for this transparency. This study may include a pilot opinion survey to determine acceptability.

After service reports on transparencies procured in accordance with these interim requirements have been received, a revised set of specification requirements based again on considerations 1, 2, and 3 with the added consideration of the results of service employment may be established. With respect to considerations 1, 2, and 3, additional production experience will be available when this revision is made.

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STUDIES IN AERIAL SURVEILLANCE:
I. JULY 1954 TESTS AT FORT HUACHUCA

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INTRODUCTION

In July of 1954 the Optics and Vision Group of Project MICHIGAN conducted field tests of aerial visual surveillance at the Army Electronic Proving Ground, Fort Huachuca, Arizona. The primary purpose of these tests was to compare the performance of a surveillance pilot with that of an observer without pilotage responsibilities who was given the option of using certain optical aids. It was hoped that the tests might suggest, in addition, desirable features of optical aids for use in aerial battlefield surveillance. Accordingly, the experimental design was oriented toward observation of representative tactical targets from altitudes which were thought to be realistic in terms of visual surveillance tactics.

The choice of Fort Huachuca as a test site proved to be most fortunate. Field testing typically involves such a host of delays (administrative, mechanical, and meteorological), that it is a rare instance in which the test program can be conducted on schedule and concluded satisfactorily. Owing to the unusually fine cooperation extended us by the personnel at Fort Huachuca, the good logistic support of the program, the efficient maintenance of our aircraft, and the remarkable reliability of the Arizona climate, we were able to complete sixteen different target situations in nine days. A considerable debt is due, in particular, to the Battlefield Surveillance Group under Colonel George Moynahan, and to the 505th Army Signal Group which provided personnel and vehicles for our use.

TERRAIN AND TARGETS

Two hundred men and 32 vehicles were used as targets. These were deployed in various arrangements to simulate actual battlefield conditions, and the number, concealment, dispersement, and terrain background were changed from test to test in order to imitate as wide an assortment of tactical situations as possible. The Fort Huachuca area possesses a wide variety of terrains: wooded areas, desert, ravines, and scrub growth, so that we were able to place our targets against a number of terrain backgrounds. Moreover, the desert air in that region is exceptionally clear, so that at the altitudes flown, there was negligible attenuation of target contrast.

On the basis of a survey of the local area, two target areas were chosen, as shown in Figure 1. Each area is approximately 1000 meters wide with the length of the East-West area (Area I) 9000 meters and that of the North-South area (Area II) 6750 meters. The East-West area is characterized by open and wooded regions, dirt roads, slopes, dry river beds, and desert. It was in this area that nearly all of the target situations were arranged. The North-South area was used on only one day, for troops in defilade in Sycamore Canyon.

From day to day the 200 troops and 32 vehicles were deployed in the target area in various ways. Generally, some of the targets were concealed under trees, in tree shadows,

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and the dispersal varied between missions. Twelve jeeps, ten 3/4-ton and ten 1-1/2-ton trucks, 50% of each type equipped with trailers, served as the vehicular targets. A complete schedule of target situations is presented in Table I.

No attempt was made to structure the target deployment beyond placing the troops and vehicles within the prescribed rectangular limits; it was left to the ground commander to arrange realistic combat patterns. It was necessary, as will become evident, for all targets to be held static during a mission.

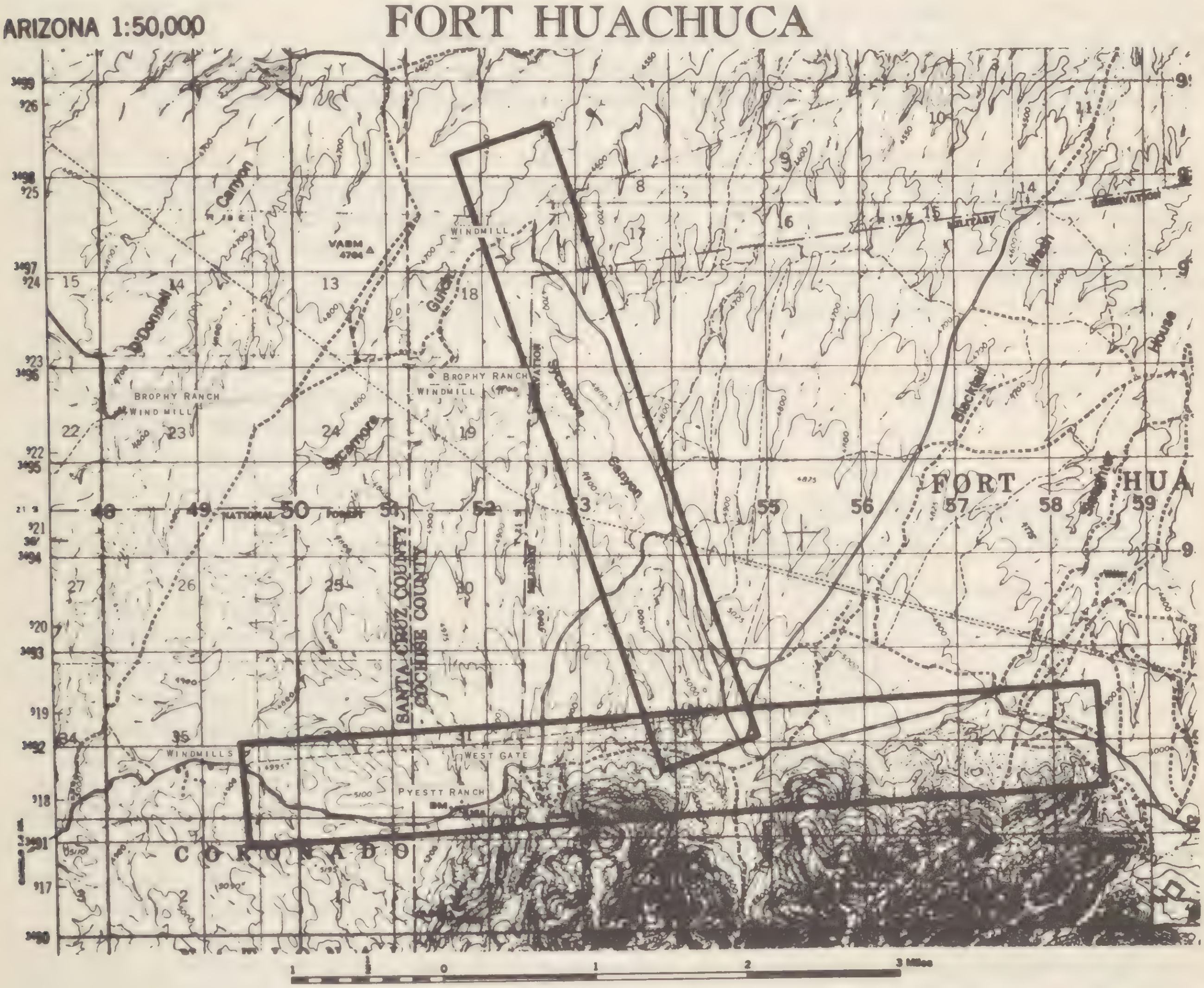

Figure 1. Target Area I (East-West Area) and Target Area II (North-South Area), Fort Huachuca.

SURVEILLANCE AIRCRAFT AND FLIGHT PLAN

Observations during the tests were made from a single RB-26 aircraft, modified for the purpose by constructing two comfortable viewing positions for the non-pilot observer. Use of the two positions, one in the bomb bay and the other in the nose, was varied from test to test so that the non-pilot observer would have the opportunity to observe in each position equally. The two positions were arranged partially because it was not apparent,

a priori which position was superior and partially to permit unrecorded observations by a member of the research staff.

In addition, a supplementary intercommunication system was installed to allow independent recording of verbal reports from either observer or pilot, by means of two tape recorders in the aft compartment of the ship.

The arrangement of pilot, observers, and experimenter is shown diagrammatically in Figure 2. The bomb bay position was constructed by adding a plywood floor and an inclined "picture window" of high quality Plexiglass to the aircraft structure. In each observing location, there was a narrow airfoam bed which gave support to the observer's chest, stomach, and legs, while leaving his arms free for movement in use of the optical aids. Shaded lines in Figure 2 indicate special tape-recorder channels to the aft compartment.

The non-pilot observer and the pilot reported the number and kind of targets seen during each pass over the target area, and these responses were tape-recorded by the experimenter in the aft compartment. No intercommunication was possible between observers during the runs, and only the experimenter had knowledge of all observers' performance. Radio communication with one of the target jeeps was maintained so that instructions could be relayed from the experimenter to the commander of the ground troops.

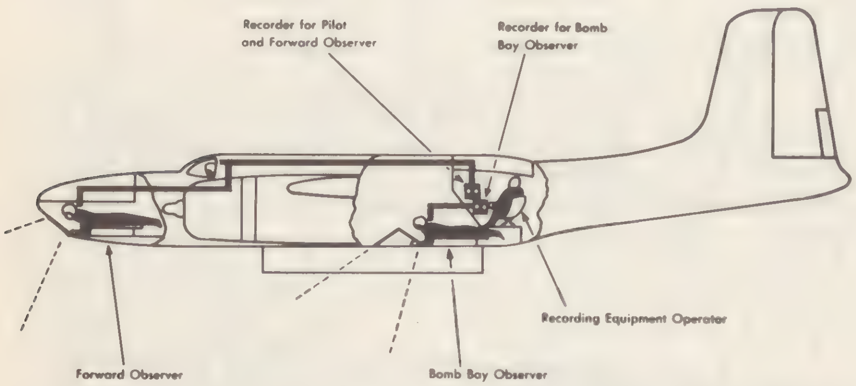

Figure 2. Schematic drawing of Modified RB-26 Aircraft.

The flight plan for each mission remained invariant throughout the experiment. Immediately upon take-off, the aircraft ascended to an altitude 8000 feet above the terrain, the ascent being accomplished over areas remote from the targets. The pilot then approached the target area, parallel to its length, and made whatever number of passes (alternating direction) were required for him to extract what he considered the maximum information from that altitude. His manner of flying was not restricted, and it generally developed that he chose a straight course somewhat to the right of the area, dipping the left wing frequently. During the pilot's observations, the other observer was required not to look at the terrain. When the pilot was satisfied that no further information could be had at that altitude, he so indicated to the experimenter, and the tape recorder was stopped. The observer then assumed his observing position, and his responses were recorded for a number of passes equal to that of the pilot. In this case, the pilot was required to fly straight and level over the midline of the target area. If, at any altitude the number of passes requested by the non-pilot observer exceeded that taken by the pilot, the pilot was required to take the necessary additional passes to bring the total into balance and equalize, thereby, the pilot-to-non-pilot opportunities for seeing. In practice, in all but a few of the very early tests, the observers indicated that two passes per altitude over the terrain strip gave them as much information as more would have. Consequently, in the over-all study approximately 95% of the cases are typified by two passes per altitude per observer in each target situation.

When the observations at the highest altitude were complete, the pilot descended to 4000 feet above the terrain and the passes were repeated. Finally, passes were made at

an altitude 2000 feet above the terrain, and all passes at these three altitudes constituted a complete mission.

OBSERVERS

Two observers served in the experiment. Both of these observers were pilots with extensive flying experience, and one in particular had had an extensive background in tactical reconnaissance.

Table I

Target Situations for Fort Huachuca Aerial Visual Surveillance Tests
July 1954

Code	Date	Type and Deployment of Targets	Area
A	7-7	32 vehicles, 50% cover, dispersed	I
B	7-8	32 vehicles, 50% cover, concentrated	I
C	7-8	32 vehicles, 10% cover, dispersed	I
D	7-9	200 men, 50% cover, concentrated	I
E	7-9	200 men, 10% cover, on roads	I
F	7-12	30 vehicles, 50% cover; 200 men, 50% cover	I
G	7-12	30 vehicles, 90% cover; 200 men, 50% cover	I
H	7-14	32 vehicles, 50% cover; 200 men, 50% cover	I
I	7-15	31 vehicles, 16 covered	I
J	7-15	31 vehicles, 6 covered	I
K	7-13	200 men, 50% in defilade	II
L	7-13	200 men, 10% in defilade	II
M	7-13	200 men, 50% in defilade	II

EXPERIMENTAL PLAN

Each evening, in consultation with the field commander, three target arrangements were laid out. These three plans were then graded as to difficulty and the middle-difficulty one selected for the morning mission. At the conclusion of the morning run, the experimenter decided on the basis of performance which of the alternative plans would be used during the afternoon mission. This decision was radioed to the ground commander via a prearranged code. An attempt was made to make the target situations difficult enought so that there would never be complete detection of the targets, even at the lowest altitude, nor would there be utter failure of detection and consequent loss of time. Beyond knowing the general types of targets to be found in Army tactical situations, the observers had no knowledge of the specified numbers, types, or dispersal of targets to be encountered in the tests. During the days immediately preceding the tests, the pilots were allowed familiarization runs over the target areas in order that the effects of increasing ease of navigation as the experiment proceeded might be minimized. During these pre-experimental runs, the pilots were able to establish useful checkpoints which facilitated the orientation procedure during actual flights.

We required that an even number of passes be made in all cases. This precaution tended to equalize the effects of shadows cast by the targets, as well as to neutralize the speed differential in the two directions, caused by winds aloft. To cite an example, the observer traveling East-to-West during a morning run, and with a 30-knot tailwind is penalized both by the obscuration of target-shadows by the targets themselves and by the relatively short time available for observation. On the 180° return pass, the headwind gives him a relative advantage of 60 knots slower, and the shadows now lie in front of the targets. Airspeed throughout the tests was held at 200 knots.

The observers were instructed to treat each individual pass as an independent event, and to report all targets seen, whether or not these had previously been reported. Reports were made concurrently with observation, so that there was no requirement to remember numbers or types of targets beyond the time necessary to verbalize the detections. The non-pilot observer was allowed, but not required, to use any of several optical aids. The observer and pilot roles were alternated on successive missions, so that on any given run one occupied the left seat of the RB-26 while the other lay prone in either the nose or the bomb bay position. Just before entering the target area, the observers began the tape recording, labeling the beginning of each section of tape verbally with his name, position in the aircraft, date, altitude, direction of pass, and time. Upon entering the target area, he began to call off targets as seen, performing individual counts on vehicles and estimating numbers of troops. Originally the plan called for a breakdown of vehicles into several categories, viz., large truck, large truck with trailer, small truck, small truck with trailer, jeep, jeep with trailer. Later analysis of the tapes showed occasional failure to discriminate between the two sizes of trucks, so that the final tabulation is in terms of the three categories: jeeps, trucks, and troops.

The optical aids used were conventional binoculars (7x50 and 8x56) and an experimental pair of image-stabilized binoculars (7x50) incorporating in their optical system magnetically damped elements which more or less effectively eliminated image motion due to aircraft vibration and muscle tremor. These binoculars represent a prototype manufactured by the Elgeet Optical Company, under contract with the Photo Reconnaissance Laboratory, Wright-Patterson Air Force Base. They were kindly loaned to the Project for evaluation in these and other field tests.

Motion sickness, a serious concomitant of the use of hand-held optical devices in aircraft, was successfully prevented by the routine administration of Chlorpromazine. This new drug, while highly effective in the prevention of nausea, appeared to have none of the undesirable side-effects (drowsiness, etc.) exhibited by Dramamine and other of the older preparations.

The exact number and position of targets during a mission was recorded on a map overlay. This was accomplished by an assistant who flew low over the terrain in an L-19 aircraft at extremely low altitudes while the targets were held in position. Contemporaneously with each pass by the RB-26, the illumination situation on the ground was monitored by a photographic photometer which measured the incident illumination at approximately the midpoint of the target area. The illumination situation proved to be so stable from pass to pass, however, that the data from this device need not be considered in the data analysis, since it was included primarily to show changes which might bias the observers' results.

Due to exigencies of weather, it was not always possible to fly the highest altitude because of occasional scattered clouds lying between 4000 and 8000 feet above the terrain. In these cases, the only undesired result was that our data were reduced correspondingly, since complete target pickup was attained in only one instance (E, 2000 feet).

RESULTS

Comparison of Pilot with Non-Pilot Observer

Complete data from the two observers who alternated in pilot and non-pilot capacities are shown in Table II. These numbers represent percentages of targets reported in each of the three categories, and at the various altitudes flown. No attempt has been made to compare the nose with the bomb bay as a point of vantage, since the data are too sparse to permit this analysis. Target codes A through J (Area I) will be considered separately from the K, L, and M codes (Area II).

The data from Area I, codes A through J are presented graphically in Figure 3. In the case of all three categories, the non-pilot observer is seen to have reported more targets than the pilot. These differences have been subject to the Chi-square test of significance and are significant at the 0.0006 level of probability. The gains enjoyed by the non-pilot observer amount to 1.36, 2.05, and 1.50 times, for jeeps, troops, and trucks, respectively. These data represent simple averages from the lumped responses at all altitudes and target situations in the East-West area.

Inspection of the mean data from codes K, L, and M (Area II) shows a reversal of the effect; the pilot apparently having the advantage over the non-pilot observer. Several unfortunate circumstances contributed to this result, so that it is necessary to discount these figures. All three situations were run on one day, two in the morning and one in the afternoon. Due to a delay in placing the target troops in defilade, the pilot observed on his first pass the trucks leaving the area, which effectively pinpointed the troop location for him. As the results show, he was able to see the men from both lower altitudes with fair succes, and long before the observer began to see a small percentage of them. In code M, a further complication arose when, during the 2000-foot observer pass, some of the troops left their posts and converged on a spot in the terrain where a rattlesnake had been discovered. Thus they presented to the observer, easily detected moving targets. The chief reason for including these data is that they are grossly indicative of the comparative ease with which moving targets are seen. In the incident just referred to, about one-half of the troops were involved, and the observer reported 46.2 per cent seen.

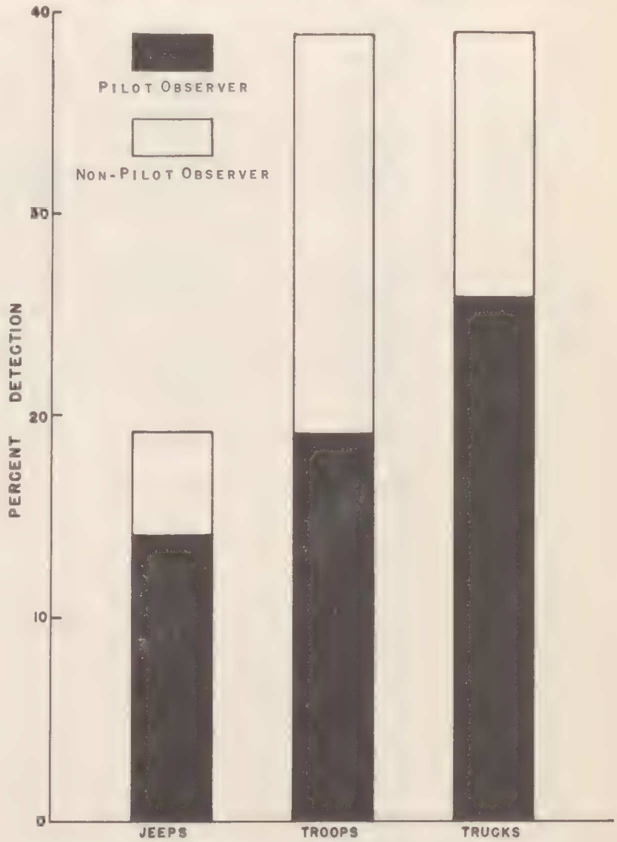

Figure 3. Detection capabilities of Pilot-Observer and Non-Pilot Observer.

DISCUSSION

We believe the differences in performance between a surveillance pilot and a non-pilot observer shown by the Fort Huachuca tests to be indicative of the <u>minimum</u> gain that is achievable, for the following reasons:

Table II

Percentage of Targets Reported

CODE	ALTITUDE	PILOT Trucks	PILOT Jeeps	PILOT Troops	NON-PILOT OBSERV. Trucks	NON-PILOT OBSERV. Jeeps	NON-PILOT OBSERV. Troops
A	8000	2.5	0	-	17.5	4.2	-
	4000	8.3	2.8	-	5.0	2.8	-
	2000	7.5	8.3	-	35.0	12.5	-
B	8000	12.5	16.6	-	?	4.2	-
	4000	21.7	11.1	-	33.0	22.2	-
	2000	40.0	41.7	-	42.5	37.5	-
C	8000	32.5	0	-	50.0	25.0	-
	4000	67.5	12.5	-	45.0	12.5	-
	2000	0	0	-	62.5	52.0	-
D	8000	-	-	0	-	-	75.0
	4000	-	-	0	-	-	57.0
	2000	-	-	45.0	-	-	75.0
E	8000	-	-	-	-	-	-
	4000	-	-	75.0	-	-	65.0
	2000	-	-	100.0	-	-	100.0
F	8000	?	?	0	15.0	0	0
	4000	15.0	10.0	20.0	15.0	15.0	12.5
	2000	27.5	20.0	20.0	42.5	15.0	37.5
G	8000	-	-	-	-	-	-
	4000	7.5	0	25.0	10.0	0	31.3
	2000	22.5	4.2	25.0	25.0	8.3	25.0
H	8000	-	-	-	-	-	-
	4000	26.2	16.6	0	52.5	29.2	50.0
	2000	20.0	16.6	0	80.0	25.0	0
I	8000	20.0	13.6	-	27.5	18.2	-
	4000	40.0	22.7	-	37.5	9.1	-
	2000	47.5	45.5	-	37.5	18.2	-
J	8000	32.5	4.5	-	32.5	22.7	-
	4000	42.5	18.2	-	80.0	54.5	-
	2000	50.0	31.8	-	72.5	45.5	-
	Mean	25.9	14.1	19.1	39.0	19.2	38.9
K	8000	-	-	0	-	-	0
	4000	-	-	75.0	-	-	0
	2000	-	-	43.8	-	-	0
L	8000	-	-	-	-	-	-
	4000	-	-	62.5	-	-	15.0
	2000	-	-	87.5	-	-	25.0
M	8000	-	-	-	-	-	-
	4000	-	-	15.0	-	-	18.8
	2000	-	-	15.0	-	-	46.2
	Mean	-	-	42.7	-	-	15.0

1. Owing to the extreme roughness of the air during most runs, it was impossible for the observer to make use of the available optical aids for more than about 10% of the time. The observers' recorded comments indicate that they wanted to use the aids, but were hampered by their inability to hold and manipulate them properly.

2. It was felt by the observers that the binoculars were of too high power, and that lower power and wider field would have resulted in easier tracking and orientation. Larger exit pupils would have been an advantage, as would greater eye-relief.

3. While the principle of image-stabilization was thought by the observers to be a most promising one, the available binoculars had far from ideal damping characteristics, so that excursions of the image resulting from air turbulence hampered observation. In addition, the binoculars tested dropped off badly in optical quality as the edges of the field were approached.

4. Although we believe the ground tactical situations were well simulated, conditions aloft failed seriously to reproduce actual combat surveillance activity. The pilot, thoroughly familiar with the terrain and the course, was relieved of the greater part of his navigational duty. (This the pilots confirmed, stating that they were able to devote almost all of their time over the target are to observation.) Nor was there any necessity for the pilot to remain alert for other aircraft or anti-aircraft fire. To the extent that our pilots were able to devote an unrealistic amount of attention to the ground targets, our data tend to minimize the inherent advantage of the non-pilot observer.

SUMMARY

A series of tests were conducted to compare the performance of a surveillance pilot with that of a non-pilot observer during aerial visual battlefield surveillance. While it was hoped that these experiments might yield quantitative information about the advantages of various optical aids, those aids available were thought to be of limited utility and their use was seriously hampered by rough air.

For those target situations in which the data are adequate, the non-pilot observer shows significantly increased ability to detect targets. For various reasons, it is thought that the differences obtained are representative only of the minimum advantage that might be expected under more realistic and typical conditions of tactical surveillance.

ABSTRACTS

a. Effect of Various Durations of Red Adaptation on the Course of Subsequent Dark Adaptation
Katz, Milton S., Ailene Morris, and Forrest L. Dimmick
Bureau of Medicine and Surgery, Department of the Navy
27 April 1954 9 pp.

"It is desirable to ascertain the usable limits of red adaptation as a substitute for dark adaptation in operational situations. The experimental data reported here pertain to the optimal duration of red light, the conditions under which it may be preferable to darkness, and the ensuing changes in dark adaptation. These data also represent a substantiation of earlier reported results.

"Thresholds were determined with 2° peripheral stimuli of .20 second duration through the course of dark adaptation. Experimental photopic-adaptation brightnesses were 16 foot-lamberts of red light for 10 minutes.

"Experiments yielded the following results: (1) Red adaptation results in a more rapid rate of early subsequent dark adaptation than does white light of the same brightness. (2) After 15 minutes of dark adaptation, a relatively stable level of sensitivity is reached which is only slightly affected by pre-adaptation conditions. After 30 minutes the thresholds give no evidence of differential effect. (3) No duration of red adaptation results in as low a threshold as a like duration of darkness."

b. Some Determinants of the Threshold for Visual Form
Bitterman, M. E., and John Krauskopf
University of Texas
September, 1954 34 pp.

"A diffusion model for visual form perception was derived from the Kohler-Wallach theory of figural after-effects. Implications of the model were tested in experiments designed to measure foveal form and brightness thresholds (for luminous figures briefly exposed in a dark room) in terms of intensity of illumination. Form and brightness thresholds were found to vary inversely with exposure-time and with area. Form thresholds varied also with the magnitude of critical detail. Data on the pre-threshold appearance of selected forms were related to results obtained with a physical diffusion model. Preliminary findings on variations in critical flicker frequency with form and on changes in size at threshold levels of illumination also were reported."

c. A Moving Target Optical Projector for Use in Air Traffic Control Research
Allen, Merrill J., Paul M. Fitts, and Alec J. Slivinske
Aviation Psychology Laboratory, The Ohio State University Research Foundation
January, 1954 8 pp.

"The specifications and design of a moving target optical projector are described. This projector was specifically designed to meet the requirements of a versatile research

apparatus in human engineering studies of air traffic control systems based upon ground displays of radar derived information. Although a few other optical simulators for air traffic control have been developed, none of these appear to offer all the advantages of the present one. The most important features of the simulator unit herein described are: (1) the linearity and precision of target movement which can be obtained without distortion or loss of focus of the image, (2) the flexibility of coding provided for the target image and the area immediately surrounding each image, and (3) flexibility in providing a simulated one-man display or a large projection screen which can be used by several controllers.

"The projector can be used single or a large number can be used together. It can provide a static display, or when connected with a suitable course generator, it can produce a moving target display.

"The projector also has potential future use in an actual traffic-control center."

d. <u>The Effect of an Improved Orientation Aid on Target Acquisition with the Hemispheric Sight</u>
Wyckoff, L. B., C. S. Bridgman, and L. Tabory
University of Wisconsin
January, 1954 6 pp.

"This experiment is part of an investigation of the problem of orientation in periscopic-type sights. The problem, briefly stated, is that an operator looking through the sight has no immediate indication of where the sight is pointed, and thus may not know which way to move it to pick up a target, the position of which is known. The present experiment was designed to test the effect of a simple orientation aid on the speed of slewing to and acquiring targets which have been spotted outside the sight. Subjects were tested on slewing and acquisition of a series of stationary targets, using "velocity" hand controls. Two groups of subjects were tested, one with and one without the orientation aid. The aid consisted of eight illuminated lines radiating from the center of the target space and stationary with respect to the target space. This aid, although actually presented in the target space, simulated an aid which could be incorporated as a moving reticle in the focal plane of the sight.

"Subjects were tested for a period of eight daily sessions. The results indicate that the subjects were performing at or near asymptotic levels at the end of this training. The group using the orientation aid showed superior performance throughout, requiring approximately 60 per cent as much time per target as the control group at all stages of practice."

e. <u>Suitability of the Gray Instrument Panel for Use in USAF Aircraft</u>
Lacey, Robert J.
WADC, Air Research & Development Command
Wright-Patterson Air Force Base, Ohio
23 April 1954 17 pp.

A. <u>PURPOSE</u>

1. To present the results of a study conducted jointly by the Aero Medical Laboratory and the Equipment Laboratory, Wright Air Development Center, and the conclusions reached regarding the proposal to change the instrument panel color from black to dark gray. (This work was transferred from the Equipment Laboratory to the Aircraft Laboratory.)

B. Factual Data

2. In June 1953 the above study was initiated to determine the functional suitability and pilot acceptance of the gray panel. Captain R. J. Lacey, Captain C. M. Seeger, and Mr. G. Weatherspoon served jointly as project engineers. A resume of the study and the results are presented in Appendix I.

3. A questionnaire was used to gather data from pilots flying aircraft equipped with a gray panel. A copy of this questionnaire is contained in Appendix II.

4. Comments of the pilots, both pro and con, submitted in addition to the questionnaire answers, are contained in Appendix III.

5. Comments from other Air Force bases and aircraft manufacturers relative to the suitability and acceptance of the gray panel are given in Appendix IV.

C. Conclusions

6. The gray instrument panel is functionally suitable for USAF aircraft and is highly acceptable to Air Force pilots.

D. Recommendations

7. That the Instrument Branch, Aircraft Laboratory, take necessary action to amend pertinent specifications to reflect a requirement for the gray instrument panel.

8. That the Psychology Branch, Aero Medical Laboratory, take necessary action to amend the Handbook of Instructions for Aircraft Designers to reflect a requirement for the gray instrument panel.

9. That the color used for the gray panel should be dark gray, color No. 3520, Specification TT-C-595.

f. Sun Position Calculator
(Instructions for making a paper paste-up and three examples to show how it can be used).
Concealment and Detection Project
U.S. Navy Electronics Laboratory
San Diego, California

"In addition to finding the natural illumination, which is covered by the book of charts, there are other needs for calculating the sun's position at any given time and place. The two sheets enclosed contain three of the five components necessary for constructing a sun position calculator. The fourth and fifth components are an ordinary T square and triangle. The construction of the computer will first be described and then the procedure for determining the sun's position: altitude and azimuth. Both the construction and the calculation are really simple, even though the descriptions may sound complicated."

g. <u>A Survey of Research on Improvement in Perceptual Judgments as a Function of Controlled Practice and Training</u>
Gibson, Eleanor J.
Cornell University
HRRC - Research Bulletin 53-45
Lackland Air Force Base, Texas
November, 1953 66 pp.

"In spite of a long history of research on problems of learning, current textbooks of psychology contain little information relating perceptual judgments to learning. That there is a problem for the learning theorist in the educability of perception is clear from many "real life" instances, such as the sensory skills of the blind, who have, presumably, been motivated to acquire greater acuteness in smell, touch, and hearing than persons with normal vision. Dallenbach and his co-workers have shown conclusively that the "facial vision" of the blind can be attributed to their learning to perceive and respond to minute changes in the reflected sounds originating from their own actions (156, 198, 24). Furthermore, during World War II, a need developed in many areas for knowing the potential perceptual skill of a man in judging such aspects of the world as the size, distance, angle and speed of obstacles, targets, and other objects in the environment. Often, the available level of skill left much to be desired and the question at once arose whether training could improve it. The kind of practice which will be most effective in increasing the skill of perceptual judgments is obviously a problem for the learning psychologist.

" It is the purpose of the present review to bring together available facts which show the effects of training on perceptual judgments, with the hope that some specific questions may be answered. Can perception be rendered more acute by training, in the sense that the observer or subject comes to discriminate smaller differences in stimulation? Can perceptual judgments of single stimuli come to be in more precise correspondence with physical scales? Can perception be rendered more accurate under conditions of reduced or impoverished stimulation, such as dim light or short duration of exposure? These are all practical questions, both in the sense of having immediate applicability and in the sense that the psychologist has the methods needed for answering them. The answers can be looked for in experiments which control and vary the frequency of practice (as well as other parameters of the learning experiment, such as kind and quantity of reinforcement). The perceptual judgments of the subject, the dependent variable, can be obtained and measured by the techniques of psychophysics.

"The studies chosen for report are limited by these questions to ones which deliberately manipulate practice in the experimental situation, or at least quantify practice which took place outside it. Other limitations should be noted. The effect of practice on judgments primarily of interest for reasons of physiological explanation have not been included; for instance, flicker fusion, though it may, apparently, show threshold changes as a function of practice (202). Experiments on animals are omitted, except in a few cases where they happen to suggest general principles, because it is too hard to disentangle the learning which is really due to perceptual practice and that which is due to learning the nature of the task and the response categories demanded by the experimenter. This latter factor, in human experiments, may play a role, but it is usually controlled satisfactorily by the preliminary instructions given the observer. It will be noted that very few experiments are reported in which the observer designated his judgment by a motor response other than a verbal one. This is not a systematically defensible omission in itself, but unfortunately, the more complex the motor response required, the less clear it becomes whether any perceptual learning has taken place. The "deprivation" experiments are omitted, of course. They are in a sense the reciprocal of the cases which are of interest here. Normal practice is prevented by temporary immobilization or sensory deprivation, but practice itself is not varied.

"This formulation of the problem of perceptual learning will be referred to as the problem of improvement in perception. The criterion of improvement will be defined in terms of veridical judgment, that is, evaluation of the judgment in terms of standards known to the experimenter by virtue of the physical yardsticks available to him. If an observer is being trained to estimate angles in a gunnery course, the measure of his learning is given by the deviation of his estimates from the true angle as defined by some measuring instrument such as a protractor. Improvement is arbitrarily defined, then, as closer, more precise, more immediate approximation of the observer's judgment to the appropriate physical standard or measure. This definition means that some kinds of judgment, such as Rorschach responses, are excluded, since there is no way of scaling "rightness" or "wrongness" and plotting a learning curve. Highly personalized perception, while certainly affected by the subject's past experience (14), is irrelevant for the problem as stated, owing to the absence of a criterion which permits measurement of learning.

"Practice, for present purposes, will be defined as any controlled activity of a subject which involves repeated perception of the test stimuli or ones similar to them. This definition assumes attention on the part of the subject, but it deliberately omits any requirement of reinforcement or correction or reward. The role of these factors will be examined in the light of the evidence.

"The experiments reviewed will be grouped according to the effects of practice on (a) acuity, (b) upper and lower limens, (c) color discrimination, (d) perception under conditions of impoverished stimulation, (e) relative discrimination, and (f) absolute judgment. This grouping is primarily determined by the operations involved in the securing of the subject's judgment since these conditions are likely to affect the resultant learning."

h. Report on General Purpose Sunglasses Submitted by Ship's Store Office
Memorandum Report No. 54-3
Medical Research Laboratory
U.S. Naval Submarine Base, New London
2 April 1954 6 pp.

"Data Requested: Testing of sunglasses and an evaluation of their suitability for resale to Navy personnel.

"Requested by: U.S. Navy Ship's Store Office ltrs NB7/J14 R(D3)JA: aa 1-1 of 1 Dec. 1953, NB 7/J14 R(D3) JA:pc 4/5 of 5 Jan. 1954, NP (13)/J14Ds JA:af (P) of 11 Feb. 1954, and NP (13)/J14 R(D3) JA:mw (P) of 10 Mar. 1954.

"Material submitted: Thirty-one sunglasses (samples of four sunglass manufacturers).

"Tests conducted at MRL: Glasses were tested for the qualities specified in Medical Research Laboratory Memorandum Report 52-6, "Requirements for General Purpose Sunglasses for Over-the-Counter Sale." The following tests were run:

"1. Visible per cent Transmission - using a Macbeth Daylight Lamp and a calibrated Weston Foot-Candle Meter with a Barrier Layer Cell.

"2. Lens Size - using the New London Scale of Lens Size.

"3. Per cent Purity (Color) - using a Macbeth Daylight Lamp, a Bausch & Lomb Color Comparator, Munsell color standards, and the C.I.E. Method.

"4. Infrared Per cent Transmission - using a 15-watt lamp source, Photovolt Model 501-M with a D cell, and filter 5263 for absorbing ultraviolet and visible light.

"5. Base Curvature - using a Geneva Lens Measure.

"6. Refractive Power - using an American Optical Company Lensometer.

"7. Prismatic Deviation - using the telescopic method with a 10-power telescope focused on a calibrated test chart at a 35-foot distance.

"8. and 9. Grade of Polish and Surface Examination - using a narrow incidence light and a black box with viewing aperture.

"10. Strain - using an American Optical Company Colmascope and a Pioneer Scientific Corporation Polaroid Polariscope Model 3C."

i. Report on American Optical Company Goggle No. 88
Memorandum Report No. 54-6
Medical Research Laboratory
U.S. Naval Submarine Base, New London
18 May 1954 3 pp.

"Data Requested - An evaluation to determine suitability for general procurement.

"Requested by - Chief, Bureau of Aeronautics per BuAer ltr Aer-AE-14/9 of 26 Feb. 1954.

"Material submitted - Two (2) pairs of American Optical Company Goggle No. 88.

"Tests conducted at MRL -

"1. Spectral Transmittance:

a. Visible region: with a Beckman Spectrophotometer; and with a calibrated Weston Foot-Candle Meter with a barrier layer cell, using a Macbeth Daylight lamp.

b. Erythemal band: with a Beckman Spectrophotometer.

c. Infrared region: with a Beckman Spectrophotometer, and with a Photovolt Model 501-M with a D cell and filter 5263 for absorbing ultraviolet and visible, using a 15-watt lamp source.

"2. Per cent Purity (Color): with a Beckman Spectrophotometer, calculated by the C.I.E. Method.

"3. Lens Size: with a New London Scale of Lens Size.

"4. Base Curvature: with a Geneva Lens Measure.

"5. Refractive Power: with an American Optical Company Lensometer.

"6. Prismatic Deviation: with a 10-power telescope focused on a calibrated test chart at a 35-foot distance.

"7. Lens Thickness: with an American Optical Company Thickness Gauge.

"8. Surface Examination: with a narrow incidence light and a black box with viewing aperture.

"9. Abrasion Resistance: with rubber abraders and high-linen-content paper."

j. <u>Report on Pre-Production Samples of Flying Goggles, Type II</u>
Memorandum Report No. 54-8
Medical Research Laboratory
U.S. Naval Submarine Base, New London
11 June 1954 3 pp.

"<u>Data Requested</u>: Tests on pre-production samples as specified in JAN-G-635 (14 July 1948) with the modifications listed in Contract N383s-99635.

"<u>Authorized by</u>: Bureau of Medicine and Surgery letter BUMED-714 NB7/M3-2 of 13 Jan 1953.

"Material submitted: Five Goggle Sets, Flying - Type II, Pre-production samples, American Optical Company, Contract N383s-99635. Each goggle set includes one goggle frame fitted with Class 4 Clear Lens plus one Class 7 Neutral Gray Lens. Also submitted were two yards of webbing used in the goggle strap."

k. <u>The Visual Discrimination of Velocity as a Function of the Rate of Movement and other Factors</u>
Brown, R. H.
Psychology Branch, Radio Division III
Naval Research Laboratory, Washington, D.C.
26 January 1954 10 pp.

"As part of its program of basic research on tracking, the Psychology Branch, Radio Division III, is conducting experiments to determine systematically how man discriminates velocity and acceleration. The method used involves the simplest discrimination man can make to visual movement. The observer, presented with a spot traveling at a controlled speed, reports its direction. The present report describes the results of an experiment in which eight observers made 120 discriminations when the spot was moving at each of ten speeds.

"Analysis of the results yields the following conclusions: (1) Within limits, as the speed with which an object travels increases, the frequency with which man discriminates its direction also increases. This frequency-of-discrimination function may be described as a logarithmic normal probability integral of the rate of movement, and the mean and standard deviation may be taken as representative of the function for a given observer. (2) Secondary and essentially irrelevant factors in the experimental situation do not affect the discrimination. (3) Man's sensitivity to differences in velocity improves with velocity at slow speeds. (4) The results of this experiment provide for a fuller understanding of man's behavior in tracking."

l. A Comparison of Ortho-Rater and Wall Chart Visual Acuity Measurements
PRB Research Note 10
Gordon, Donald A., Henry J. Zagorski, and Joseph Zeidner
The Adjutant General's Office, Personnel Research Branch
Department of the Army, Washington, D.C.

"Tests of visual acuity typically use wall chart targets presented in testing alleys. Recently, devices or instruments which optically simulate distance are being used more and more in acuity testing. Such instruments have the advantage over wall charts of requiring less space and allowing for easier changing of targets. They also provide fixed and uniform conditions of lighting and distance. A greater number of visual functions can be tested in the same instrument.

"However, before an instrument is adopted for operational use, it is desirable to compare scores on it with scores on wall charts now in use. This study compares the Ortho-Rater instrument and the wall chart methods of presentation in terms of difficulty-level, reliability, and visual functions tested.

"Letter and modified Landolt ring tests were administered in an Ortho-Rater and also on wall charts to 117 soldiers. Average scores and levels of difficulty were practically the same for the two methods of presentation. Ortho-Rater scores were more reliable. The same visual functions were measured by both methods.

"It would appear that a relatively more convenient instrument method may be substituted for the wall chart method when presenting targets of the type used in this study."

m. Herkenbaarheid van cijfers (Recognizability of Figures
door J. J. Vos.
Werkgroep Waarneming
Rijksverdedigingsorganisatie T.N.O.
Rapport No. WW1954-4 11 pp.

"The influence of different factors (type, line-width, width, colour, contrast, lighting) on the recognizability of figures is examined in experiments with test subjects.

"The results are given in Tables and discussed. A comparison with results of other investigators is made."

n. Luminance Thresholds During Dark Adaptation Following Preadaptation to Cathode Tube Displays
Herrick, Robert M., A. Leonard Diamond, and Margaret P. Kuhns
Columbia University
Wright Air Development Center
WADC Technical Report 52-260
December, 1952 11 pp.

"With the identification of the position of a luminous dial pointer as the threshold criterion, luminance thresholds were determined at various times during dark adaptation following preadaptation to Cathode Ray Tube displays. Each display consisted of a vertical trace line which traversed the Cathode Ray Tube screen at one of three rates. Dark adaptation curves, obtained after adaptation to the different displays are superimposed; initial thresholds are relatively low $\cdot$(-2.0 log mL); and dark adaptation is essentially complete in five minutes. The findings are interpreted to indicate that in certain Air Force applications, viewing such displays causes a definite temporary loss in the observer's ability to read instrument dials and to perceive objects external to the aircraft."

o. Effect of Flashes of Light Through the Closed Eyelid: Part 1. Preservation of Dark Adaptation During a Flash by Closing the Eyelids
Fry, Glenn A., and Norman Ihrig
The Ohio State University Research Foundation
Wright Air Development Center
WADC Technical Report 53-159
March, 1953 36 pp.

"The major objective of the study was to investigate means of protecting one of the eyes during a short flash in order to preserve its state of dark adaptation. The second eye is used for critical seeing during the flash and the protected eye takes over following the flash. No effect was found to be transferred during a flash from the eye kept open to the closed eye.

"The typical flash considered is one which produces 125 foot-candles in the plane of the pupil for a period of three seconds.

"The effect of such a flash upon the state of adaptation was measured by tracing the recovery of the ability to see a narrow black bar on an 8^{o} field centered at a point 5^{o} to the right of the fixation point.

"A flash of 125 foot-candles produces a marked effect on adaptation. It is necessary to drop the level of illuminance three to four log units to abolish the effect.

"An after-image method was devised for measuring the retinal illuminance produced by light incident on the closed eyelid. It was found for the average subject that an illuminance of one foot-candle on the passively closed eyelid produces a retinal illuminance of approximately three trolands.

"This can be reduced by one-half log unit by tightly closing the lids."

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